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**Compendium of Meteorology
Scientific Issues of
1950 Still Outstanding**

William W. Vaughan

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COMPENDIUM OF METEOROLOGY SCIENTIFIC ISSUES OF 1950 STILL OUTSTANDING

I. INTRODUCTION

In the latter part of the 1940's the Geophysics Research Division of the Air Force Cambridge Research Center (now designated the Air Force Geophysics Laboratory) commissioned the American Meteorological Society to prepare a survey of the current state of meteorology. The product of this endeavor was published in 1951 by the American Meteorological Society as the Compendium of Meteorology (Anon. 1951). Most of us who undertook our formal training in meteorology during the 1950's became rather well acquainted with this seven pound (it seemed like more) book and found it to be an invaluable source of information on our current knowledge of the atmosphere. It was produced under the direction of a committee chaired by Henry Houghton. The members were Horace Byers, Helmut Landberg, Henry Wexler, Bernard Haurwitz, Athelstan Spilhaus, and Hurd Willett. The preface was written by Thomas Malone. In the following paragraphs I have used, and sometimes paraphrased, Thomas Malone's most descriptive remarks from the preface which outlined the Compendium's development and contents very well.

"The purpose of the Compendium of Meteorology was to take stock of the position of meteorology in the late 1940's, to summarize and appraise the knowledge which untiring research has been able to wrest from nature during past years, and to indicate the avenues of further study and research which need to be explored in order to extend the frontiers of our knowledge. No one can read the papers in the Compendium without experiencing the feeling that this was the threshold of an exciting era of meteorological history in which significant advancements were possible toward a better understanding of the physical laws which govern the workings of the atmosphere. (If one reflects on the past thirty-five years of meteorological achievements, it is apparent that the authors correctly perceived the future.) However, that this progress was not made without some difficulty is quite apparent from the number of unsolved problems which still remain as a challenge to the research worker in spite of the centuries of concentrated study which have been devoted to the nature and behavior of the atmosphere.

Capt. H. T. Orville, U.S.N. (Ret.), president of the Society from 1948 to 1950, appointed the Committee on the Compendium of Meteorology, under the chairmanship of Professor H. G. Houghton, to organize and supervise the undertaking. This committee sought and obtained suggestions from many eminent meteorologists and, in a series of meetings in the latter part of 1948, formulated the specific nature of the present work. One hundred and two authors were commissioned in 1949 to prepare the one hundred and eight articles which comprise this book. In most cases, more than one author was invited to contribute on a single broad topic. This was done intentionally, despite some slight duplication, to insure the presentation of specialized aspects of certain general subjects and to provide ample opportunity for the exposition of different viewpoints.

A logical grouping of papers on related topics resulted in a division of the book into twenty-five sections. Since the composition and physics of the atmosphere are fundamental to a consideration of meteorological problems, the first part of the book is concerned with the field generally referred to as physical meteorology. Then comes a discussion of the upper atmosphere, followed by a section which deals with extraterrestrial effects on the atmosphere and with the meteorology of other planets. The section in which is presented a general discussion of the dynamics of the atmosphere is followed by three

sections which treat various aspects of the primary, secondary, and tertiary circulations, respectively. These papers provided a logical introduction to the treatment of synoptic meteorology and weather forecasting and to the discussions of the meteorology of the tropical and polar regions and the section on climatology. Hydrometeorology, marine meteorology, biological and chemical meteorology, and atmospheric pollution are fields in which the interests of meteorologists meet those of hydrologists, oceanographers, biologists and chemists, and engineers, and these topics are treated in that order. The topics of clouds, fog, and aircraft icing were included in a single section because of their obvious relationship to one another. The discussions of meteorological instruments and laboratory investigations and the theory of radiometeorology and microseisms and their applications to meteorological problems constitute the final sections."

II. DISCUSSION

This paper was motivated by an interest in evaluating the progress made since the late 1940's on the specific topics of further study and research which authors of the papers in the Compendium of Meteorology identified as needing to be explored in order to extend the frontiers of our knowledge in meteorology. It was the intent to compare the statements made by the authors on research needs with those made by the authors of recent documents published by the National Academy of Science and committees sponsored by various government agencies and organizations. This developed into a formidable undertaking. Given the mass of literature published since the 1940's on meteorology, it became an impossible task for me to review the material and assess the findings in terms of progress made on the studies and research needs identified by authors of the papers. However, given the resources expended toward satisfying these needs and the obvious interest by scientists and scientific program managers to evaluate the progress achieved from these resources, a decision was reached to identify the study and research needs as noted by the authors and let the reader determine for himself the progress made toward their fulfillment. In some cases the needs will certainly be as valid today as they were in 1951 when the Compendium of Meteorology was published. In other cases one will easily be able to identify examples of significant progress. Personally, I was surprised at the number of study and research needs which, in my opinion, are still current today after thirty-five years of rather extensive research. Of course, the results of much research has been the identification of new and more complex research topics. Thus, there still remains a wealth of scientific problems for those coming into the field to solve.

The following sections of the paper are organized according to the twenty-five sections of the Compendium of Meteorology. Some authors were rather liberal with their identification of issues and needs, whereas for others it was more difficult to identify their thoughts on the subject and some topics may have been missed in the review of their papers. To the degree practical the wording of the various authors has been retained. The number in parenthesis at the end of each topic refers to the page in the Compendium of Meteorology where this statement may be found.

A. COMPOSITION OF THE ATMOSPHERE

1. The Composition of the Atmosphere (E. Glueckauf)

- a. A redetermination of the best values of oxygen and carbon dioxide is particularly desirable in order to get any long term variations of the oxygen (and carbon dioxide) content of the air. (9)

- b. The unexplained oxygen values of Lockhart and Court (Glueckauf and Paneth, 1946) in the Antarctic should be either confirmed or refuted. (9)
- c. The high carbon dioxide values observed by Krogh (1904) in certain arctic regions also need to be either confirmed or refuted. (9)
- d. Collender's (1940) suggestion that carbon dioxide increase during this century due to industrial carbon dioxide production should be subject to experimental verification by modern techniques. (9)
- e. The percentage of methane in air requires more accurate determination and the question of its production requires further study. (9)
- f. Our knowledge of the hydrogen content of air is so far inadequate. (9)
- g. Large gaps still exist in our knowledge of atmospheric ozone near the ground. Its dependence on weather conditions requires much more systematic investigation, particularly with reference to its vertical distribution. The increased occurrence of ozone near cloud levels and its connection with thunder clouds also require more detailed investigation, including a study of its possible mode of generation under such conditions. (9)
- h. Further confirmation by rocket data is desirable of the hypothesis that the upper atmosphere has essentially the same composition as that found at the ground, at least up to heights of 70 km. (9)
- i. Brewer's (1949) hypothesis of an air circulation involving movement of air into the stratosphere at the equator followed by slow poleward movement in the stratosphere, accompanied by a slow sinking movement in the temperate and polar regions as an explanation of turbulent mixing in the stratosphere requires experimental confirmation. (9)

B. RADIATION

- 1. Solar Radiant Energy and Its Modification by the Earth and Its Atmosphere (S. Fritz)
 - a. In the solar spectrum no measurements seems to have been made in the region from $24\ \mu$ to 1 cm. (15)
 - b. Direct measurements of the suggested short-lived large fluctuations in the meteorologically important spectral region of 2000-2800 Å are needed to determine their magnitude. Measurements at somewhat larger wavelengths, for example 3200 Å (Pettit, 1932), indicate solar controlled fluctuations but doubts have been raised about the reality of their magnitude. (17)
 - c. There has been considerable controversy regarding the reality of the variations shown by solar-constant measurements. This controversy may be resolved best by making measurements from a satellite stationed outside the Earth's atmosphere. However, a more important parameter to measure is the Earth's albedo. From the meteorological viewpoint the predominant interest is not in solar energy variations as such but in the amount of energy absorbed by the Earth and its atmosphere, and in the variation of this amount. (19, 25)

- d. It would be desirable to measure the ratio for nonspectral radiation with varying atmospheric transmissions or turbidity factors. (25)
- e. Is it justifiable as a first approximation to assume that the variation of incoming solar energy in summer predominates over other effects, such as variations in outgoing radiation? (30)
- f. It will be highly desirable to measure the spectral intensity distribution of radiant energy in the 2300-2800 Å band at frequent intervals. Such measurements may determine whether current ideas regarding solar control of weather through heating of ozone have any basis. Until measurements are made of the variation of solar ultraviolet radiation which reaches the top of the ozone layer, and the variation of temperature there, we cannot be sure that solar variation is heating the ozone layer significantly above its normal temperature. (16, 31)
- g. Some measurements suggest large absorption of solar energy by clouds and it would be desirable to investigate the absorption further. (31)
- h. The excess or deficit of absorbed solar radiation by comparison with the normal absorbed radiation should also significantly influence the weather elements averaged over relatively short periods. Whether a week, a month, a season, or longer is the required "relatively short period" remains to be investigated. (31)

2. Long-Wave Radiation (F. Möller)

- a. Absorption or emission of water-vapor layers of limited thickness must be checked by laboratory and free-air experiments. Available measurements seem insufficient to explain the variation with temperature that results from the variation of the observed atmosphere radiation. (47)
- b. Long-wave radiation, particularly in the free atmosphere, must be measured. (47)
- c. Adequate data concerning the content of water vapor and carbon dioxide of the upper troposphere and lower stratosphere are needed for investigation of tropospheric radiation. Measurements are needed in such numbers that radiation changes with the weather situation become clear. (48)
- d. The influences of the geographic latitude and of continents and oceans on the content of water vapor and carbon dioxide must be determined. (48)
- e. The upper cloud boundary for various weather patterns and various types of climate needs to be determined. (48)
- f. The influence of pressure on the absorption by carbon dioxide and ozone in the 15 μ band must still be investigated in the laboratory for application to the study of the radiation processes in the region of the tropopause. (48)

3. Actinometric Measurements (A. Ångström)

- a. Measurements are needed, using an actinometer network, to solve the important problem concerning the energy exchange within the Earth's atmosphere and factors influencing it. Without a thorough knowledge of these factors, their distribution and variations, all speculations on climate variations are reduced to rather vague guesses. (55)

- b. A clear separation between scattering and absorption is an important problem, closely connected with the climate variations, concerning the transmission of the atmosphere and its fluctuations. When we know the scattering coefficient and its variations, we will be able to give a much more detailed picture of the variations in the different spectral regions of the sun's radiation. (56)
- c. The outgoing "effective radiation" should be the object of a closer investigation especially with respect to its distribution over the Earth's surface. (56)

C. METEOROLOGICAL OPTICS

1. General Meteorological Optics (H. Neubeyer)

- a. An all-inclusive theory of the apparent shape of the sky is needed. (63)
- b. The problem of the mutual influence of sky shape and cloudiness estimation needs further investigation. (64)
- c. The quality of cloudiness estimations for individual cloud layers in the presence of other cloud decks needs special attention, as does the effect of the configuration of the terrestrial horizon on such estimations. (64)
- d. Unexplored is the possible effect of an observer's height above the Earth's surface on his impression of the sky shape and consequently the accuracy of his cloudiness estimate. The apparent shapes of the terrestrial surface and of cloud layers, as seen from above, deserve attention. (64)
- e. Laboratory experiments, which permit control of the variables, and theoretical study of the heat transfer rate seem desirable to expand our knowledge of mirages. (67)
- f. An exact mathematical expression of the relationship between the frequency and amplitude of apparent object motion, apparent intensity fluctuations, and chromatic effects on the one hand, and periodic time-space variation of meteorological factors on the other, remains undeveloped. (68)
- g. An investigation into the size, shape, spacing, and transport velocity of schlieren in relation to the size, distance and optical characteristics of the light source for various degrees of scintillation is needed. (68)
- h. The observations of fluctuations of colors during lightning and thunder (Pernter and Exner, 1922) need objective verification and explanation. (71)
- i. The old controversy regarding the possibility of coronas and glories in ice-crystal clouds (Humphrey, 1940) cannot be considered solved. (72)
- j. A theoretical and experimental study of inhomogeneous fogs appears of particular practical importance. (72)
- k. No complete theory of twilight phenomena exists. (74)

1. A long-range observational project on an international basis is necessary to the determination of the terrestrial or possibly cosmic origin of dust layers that periodically produce striking twilight phenomena. (76)
2. Polarization of Skylight (Z. Sekera)
 - a. There is a definite need for better equipment for measuring skylight polarization. (88)
 - b. An exact theory of twilight phenomena needs to be developed. (88)
3. Visibility In Meteorology (K. Middleton)
 - a. Serious effort should be made to clear up the uncertainty concerning the value, or range of values, of the threshold of contrast actually entering into meteorological observations of "visibility." (95)
 - b. A need exists for new instruments to measure visibility which are simple and inexpensive. (95)
 - c. A really practical method of measuring the transparency of the atmosphere as a function of height for at least a few thousand feet above ground is the leading problem. (96)

D. ATMOSPHERIC ELECTRICITY

1. Universal Aspects of Atmospheric Electricity (O. Gisk)
 - a. There is a need to locate the source of those universal aspects which are epitomized in the concept, supply current, and elucidate the mechanism which generates the supply current. (118)
 - b. Adequate quantitative descriptions of atmospheric electricity phenomena are necessary before the rationale of the subject is developed. Some of the more important observations needed include: air conductivity, counts of Aitken nuclei in thunderstorms, population of electric storm centers in progress on the Earth, air current density, electric field in vicinity of thunderstorms, electric charge distribution within storms, rate of regeneration of charge after a lightning discharge, processes of initial charge separation in a thunderstorm, and data on how the widely scattered discrete charges in a charge-cloud are mobilized for the lightning discharge. (119)
2. Ions In The Atmosphere (G. Wait and W. Parkinson)
 - a. There is need to better evaluate the rate of ionization of the atmosphere as a factor in small-ion regulation. (126)
 - b. There is an urgent need for careful experimentation designed to secure much-needed information on the role meteorological conditions play in altering the efficiency of some or all the small-ion regulating factors. (126)
 - c. Multiply charged large ions should be examined as to regularity of, and condition of, occurrence as to their effect on large ion mobility and on establishment of small ion equilibrium conditions. (126)

3. Precipitation Electricity (R. Gunn)

a. The principal practical problems are:

- 1) to describe the detailed electrical processes responsible for the production of lightning,
- 2) to describe the mechanisms responsible for the maintenance of the observed negative free charge on the surface of the Earth, and
- 3) to describe those processes that transfer free electrical charge to aircraft flying through natural precipitation and devise methods to counteract such processes. (128)

b. The more basic questions which must be answered include:

- 1) How is a free electrical charge placed on precipitation?
- 2) Why does charge of a selected sign appear principally upon the larger precipitation elements?
- 3) What are the mechanisms responsible for the separation of positive and negative charges?
- 4) How large are the electric fields so produced? (128)

4. The Lightning Discharge (J. Hagenguth)

a. More information is required on these principal problems to complete the understanding of the physical phenomena involved in lightning discharges.

- 1) Gradient at point of origin of stroke.
- 2) Gradient distribution within and beneath clouds.
- 3) Gradient at ground end of a stroke.
- 4) Existence and character of ground streamers prior to stroke contact with the ground.
- 5) Ionization processes within the stepped leader, continuous leader, and return stroke.
- 6) Ionization and deionization of the stroke channel with special reference to continuing current discharges.
- 7) Influence of ground conditions on the return-stroke process. (142)

5. Instruments and Methods For the Measurement of Atmospheric Electricity (H. Israël)

a. A need exists to extend the measurements to more than a single atmospheric-electric element. (150)

b. For investigations of the effect of austausch on atmospheric-electric conditions, a simplified case must first be attacked by means of recordings made at altitudes as high as possible. The following experiment appears to be an additional promising step in this direction. A program could be set up to obtain simultaneous records of atmospheric-electric elements at neighboring stations located at different altitudes. This would offer the possibility of observing the gradual upward penetration of the austausch effect (Israël, 1950). (151)

- c. Further investigation of the diurnal variations of atmospheric-electric elements in various air masses can be expected to furnish criteria of the degree of stability or instability of atmospheric stratification. (151)
 - d. Research in the vicinity of "generators," that is, in the region of thunderstorms, precipitation, and clouds, offers special problems; see for example, the work by Simpson (1948, 1949). (151)
 - e. Without doubt, the greatest problem of atmospheric electricity is its systematic extension into the third dimension, that is, the development of an atmospheric-electric aerology with regular determinations of the conditions existing in the free atmosphere (Israël, 1949). (151)
 - f. The exploration of the origin and propagation of high-frequency disturbances in the atmosphere (sferics) can materially aid weather reconnaissance and analysis and can be developed into an integrating component of meteorological practice. (151)
6. Radioactivity of the Atmosphere (H. Israël)
- a. The mechanism of the horizontal and vertical distribution of radioactive substances in the atmosphere needs to be established. (159)
 - b. The methodological problem of atmospheric radioactivity consists of the following.
 - 1) Substitution of measurement by automatic recordings.
 - 2) Simultaneous survey of diurnal variations of the radioactive elements in the air at several stations at various altitudes.
 - 3) An air-mass classification according to origin and age on basis of the Rn content and of Ra-to-Th-derivatives.
 - 4) Vertical cross sections of atmospheric radioactivity.
 - 5) Determination of the radioactivity of precipitation. (159)

E. CLOUD PHYSICS

1. On The Physics of Clouds and Precipitation (H. Houghton)
- a. An investigation of the factors determining the breadth of the drop-size distribution is needed. (179)
 - b. Knowledge of the ice phase in the atmosphere is inadequate. (179)
 - c. The nature and mode of action of freezing nuclei and sublimation nuclei must be determined. (179)
 - d. A complete study should be made of the growth of drops by collision in the gravitational field. (179)

- e. Instrument development is needed for measurements to determine which precipitation processes operate under various conditions and to obtain a quantitative verification of the operation of assumed processes. (179)

2. Nuclei of Atmospheric Condensation (C. Junge)

- a. The growth of nuclei, especially at humidities of less than 70 percent, and the associated problem concerning the physical structure of nuclei requires study. (185)
- b. The chemical composition of the aerosol needs to be determined. The proportion of traces of gaseous materials should also be established. (185)
- c. The performance of haze-droplet counts on a layer basis is needed to determine the contribution of maritime aerosol (sea-salt nuclei). (186)
- d. The behavior of substances of low volatility, and the influence of equilibrium and humidity in gas reactions on the concentration and size of nuclei needs to be determined. (186)
- e. The effect of humidity on coagulation needs to be studied. (186)

3. The Physics of Ice Clouds and Mixed Clouds (F. Ludham)

- a. What are the mechanisms of nucleation and properties which determine the efficiency of an ice nucleus? (194)
- b. What are the effective ice nuclei in the atmosphere and their numbers at different levels in various air masses? (194)
- c. More information is needed on the behavior of hygroscopic nuclei at low temperatures, both when they are pure and when they are contaminated by freezing nuclei. (194)
- d. The reason for the failure of cold-weather cumulus, with summit temperatures as low as -20°C , to produce showers needs to be established. (195)
- e. Little is known about the manner in which ice "splinters" are produced and their electrical charges that arise during the growth or evaporation of an ice particle. (195)
- f. Little attempt has been made to work out in detail the growth conditions of cumuliform clouds and the modifications introduced by the appearance of the ice phase and the development of precipitation. (195)
- g. The occurrence of cirrus well ahead of cold fronts is unexplained. (197)
- h. Little is known about the vertical displacement of air at high levels and more accurate measurements of humidity are required. (197)

4. Thermodynamics of Clouds (F. Möller)

- a. The effect of radiation on thunderstorms has not been clearly determined. (203)

- b. Perhaps a combination of the parcel and slice methods and a simultaneous test of the two theories would lead to different ideas about lateral entrainment in cumulus clouds. (203)
 - c. An explanation of the nocturnal shower maximum over the oceans needs to be made. (204)
 - d. The aim of further scientific investigation should be to combine all the separate stones of our mosaic into a coherent picture of the heat balance of the clouds, in particular, 1) the heat balance of the clouds in general, 2) the heat balance of the individual types of clouds, and 3) the role of the individual cloud types in the heat balance of the entire atmosphere. (205)
5. The Formation of Ice Crystals (V. Nakaya)
- a. The problem of supersaturation as stated by Bennett (1934), "the evidence is merely negative as to whether supersaturation does or does not exist, and positive evidence is urgently required," is still left unanswered. (219)
 - b. Further studies on the relation between the air temperature and the crystal form may contribute something to this new field of meteorology. (220)
6. Snow and Its Relationship To Experimental Meteorology (V. Schaefer)
- a. No methods are known at present which would lend themselves to the effective dissipation of warm fogs. (232)
 - b. Further studies on the electrical properties of snow should produce important results. (227)
 - c. A better understanding of the formation of snow in the atmosphere is needed. (221)
7. Relation of Artificial Cloud-Modification to the Production of Precipitation (R. Coons and R. Gunn)
- a. Further progress on artificial cloud-modification and the production of precipitation will depend, in no small measure, upon the invention and development of better airborne instruments suitable for making rapid determinations of the detailed characteristics of each cloud to be explored. (241)

F. THE UPPER ATMOSPHERE

1. General Aspects of Upper Atmospheric Physics (S. Mitra)

- a. The relative distributions of oxygen and atomic oxygen with height are not known with certainty and an accurate determination is needed. (256)
- b. The question at what height above 70 km, diffusive separation becomes important is of considerable interest. (256)
- c. In the ozonosphere the modes of production and distribution of ozone and the ozone equilibrium resulting therefrom are in need of further elucidation. (256)
- d. The temperature distribution in the region 70-90 km needs more accurate determination. (256)

- e. The lunar semidiurnal barometric oscillations and the corresponding magnetic variations still have their puzzles and need to be solved. (257)
- f. Further observations in different latitudes are needed to test the suggestion that periodic fluctuations in intensity of radio echoes from meteoric trails is caused by variations of wind with height (Herlofson, 1946-47). (257)
- g. How far the magnetic field of the earth influences the cross section of the ionized column needs to be established. (257)
- h. The mechanism needs to be found by which sufficient electron density, for periods of more than a minute, could be maintained against the forces of diffusion. (257)
- i. The reason for the bifurcation of the F-layer into F_1 and F_2 during daytime is not yet understood. Association between F_2 layer ionization and tropospheric weather conditions has been observed. But what is the origin of such association? No theoretical explanation of such association has yet been given. (257)
- j. The observed geomagnetic control of Region F, in the form of a belt of low ionization round the geomagnetic equator, needs much fuller investigation. (257)
- k. A complete theory of the F_2 -region is still lacking and needs to be developed. (257)
- l. Little is known on the exact nature and life history of ionization and more observational data in different latitudes are needed. (257)
- m. A closer comparative study of the effective recombination hypothesis and Martyn's (1947) hypothesis in the high ionized regions is needed to estimate the relative importance of the two in bringing agreement between observed and theoretically computed values. (257)
- n. It is very necessary to know how the phase of the ionospheric region tides varies with latitude. (258)
- o. The continuous spectrum which forms the background of the lines and bands of the night-sky light appears to have received inadequate attention and awaits further study regarding its intensity variations and origin. (258)
- p. The location and origin of the zodiacal light is still far from solved. (258)
- q. The problems of the aurorae and of the incidence of the magnetic disturbances, so closely related to each other, are only partially solved. (258)
- r. There remains the problem that while the Vegard-Kaplan bands are strong in the night sky they are comparatively faint in the auroral spectrum. (258)
- s. A more complete knowledge is needed of the electronic spectra and of the absorption coefficients of atomic nitrogen, atomic oxygen and oxygen in the extreme ultraviolet region. Also, a more detailed study by the quantum-mechanical method of the collisional cross sections of these molecules and atoms is necessary. (259)

- t. More theoretical and experimental data on the collisional processes between meteor atoms and air molecules are needed. (259)
- 2. Photochemical Processes in the Upper Atmosphere and Resultant Composition (S. Chapman)
 - a. A basic need is the determination of the composition of the upper atmosphere as well as the height-distribution of temperature and density. (273)
 - b. The study of the absorption and emission of the constituents of the upper atmosphere, by night, at twilight, and during the day will enhance our understanding of the nature and processes of chemical, electrical and energetic change there. (273)
 - c. A network of stations for radio investigation of the upper atmosphere processes on a world-wide and continuous basis throughout the sunspot cycle is needed. (273)
 - d. Many additional purely chemical and physical data are required as a basis for atmospheric theories, namely, data on the rates of various types of atomic and molecular processes, and in some cases on the temperature dependence of these rates. (273)
- 3. Ozone in the Atmosphere (P. Götz)
 - a. The continuous series of observations which were started at several locations must be carried on for prolonged periods of time and the observational network needs to be expanded, especially to the polar regions. (288)
 - b. Vertical ozone distribution, together with information concerning water vapor, could be exploited directly in connection with forecasting and would provide the material necessary for approaching the problem of radiation flow. (288)
- 4. Radiative Temperature Changes in the Ozone Layer (R. Craig)
 - a. More solar spectrum measurements are needed into the ultraviolet, perhaps to 1800 Å, to check the accuracy of the information now available and to show whether there are any significant variations of the spectrum with time. (300)
 - b. The vertical distribution of all the absorbing gases in the ozone layer are in doubt. (300)
 - c. Further study of the pressure dependence of oxygen absorption should be made in the laboratory. Also, absorption data in the infrared are urgently needed. (300)
- 5. Temperatures and Pressures in the Upper Atmosphere (H. Newell)
 - a. It would be worthwhile to compare critically the various methods of determining density, pressures and temperatures in the upper atmosphere, at least to point up systematic differences in the results. (308)
 - b. Composition, density, pressure, temperature, and wind measurements should be extended to reach different latitudes and cover various times of day and year at same times. (309)
 - c. Absorption of terrestrial and solar radiation measurements at various altitudes over a wide temporal and geographic range should be made. (309)

6. Water Vapor in the Upper Air (G. Dobson and A. Brewer)
 - a. There is an urgent need for more water vapor observations in every part of the world in all types of weather and particularly on a synoptic basis. (319)
 - b. A fully automated hygrometer for widespread use is urgently needed. (319)
7. Diffusion in the Upper Atmosphere (H. Lettau)
 - a. More plentiful and improved observations of the composition and the geophysical conditions of the upper atmosphere are needed. (332)
 - b. The eddy diffusion coefficient as a function of altitude needs to be verified more soundly to enable the composition of the stratosphere to be computed. The most promising method of direct attack requires chemical analysis of the air at levels above 15 km, especially from layers of presumably small turbulence at 20-30 km and 80-110 km approximately. (332)
 - c. More thorough and critical considerations than before of time-varying one- and three-dimensional diffusion appear necessary in order to avoid misleading results owing to oversimplification of the models used. (332)
8. The Ionosphere (S. Seaton)
 - a. There is a great need for accurate, long-continued observations of the ionosphere over all geographic locations. (340)
 - b. The various theories of the ionosphere need to be reexamined and extended to remove uncertainties now present. (340)
 - c. The region of ten to twelve degrees above and below the equator at all longitudes and both north and south polar areas are in great need of exploration. (340)
9. Night-Sky Radiations from the Upper Atmosphere (E. Hulburt)
 - a. Improved spectra of high dispersion of the night sky light should be obtained. (345)
 - b. The distribution of energy in the spectrum of the night sky should be redetermined with improved equipment. (345)
 - c. Surveys should be made over the entire sky in the several wavelength bands in order to determine the geographical distribution and nature and behavior of the variations of the luminosity. (345)
 - d. Measurements with photocells should be made from rockets fired to heights of 130 km and above in order to discover whether the rocket enters or traverses the regions of the nocturnal luminosity. (345)
10. Aurorae and Magnetic Storms (L. Harang)
 - a. If the questions on either the nature of the solar corpuscles or the physical state of the upper atmosphere could be solved independently, an important step forward would have been taken in the theory of the aurora. (354)

- b. A more reliable determination should be made of the auroral frequency curves. (354)
- c. It would be of great interest to study the horizontal extension of a single quiet auroral form, such as a homogeneous arc or band, along the auroral zone. (354)
- d. A new and promising field of research in ionization processes within the aurorae is the study of the scattering of radio waves from aurorae in the VHF-region. (354)

11. Meteors as Probes of the Upper Atmosphere (F. Whipple)

- a. The detailed processes of dissociation, ionization, detachment, diffusion, turbulence, recombination, and attachment of electrons in meteor ion columns require much more theoretical elaboration. (363)
- b. There is need for a detailed theoretical mechanism for the formations of the ion cap of short duration that follows the motion of the meteoroid. (363)
- c. There is still no proof from photographic or radio meteor studies that any meteoric bodies originate outside the solar system. (356)
- d. An acceptable theory as to the nature and origin of comets would be of value in the study of meteors. (357)
- e. Determination of atmospheric densities and seasonal effects from photographic observations of meteors can be improved by: 1) more numerous and accurate observations of meteors, 2) improved experimental determination and theoretical evaluations of the drag coefficient, heat-transfer coefficient, and the luminous efficiency factor, and 3) studies of the physical and chemical nature of meteoroids through the study of micrometeorites. (361)
- f. The detailed process of dissociation, ionization, detachment, diffusion, turbulence, recombination, and attachment of electrons in meteor ion columns require much more theoretical elaboration, since only a modest advance has been made beyond Öpik's meteor theory, (363)

12. Sound Propagation in the Atmosphere (B. Gutenberg)

- a. Determination is needed of the velocity and absorption of sound waves in rarified air at pressures down to 0.01 mb. (395)
- b. The effect of wind at various levels up to 100 km on sound propagation needs to be determined. (375)
- c. The effects of the wind component perpendicular to the direction of the sound propagation needs to be studied. (375)
- d. Determination needs to be made of additional travel-time curves for sound waves refracted in the stratosphere: 1) in various latitudes, 2) their annual period, 3) their diurnal period (no clear period has been found), and 4) correlation of results under 1) to 3) with periodicities of ozone content in the "ozonosphere." (375)
- e. The change in frequencies prevailing in sound waves with distance from source and effects of selective absorption needs to be determined. (375)

- f. Indications of dispersion of sound waves under various conditions needs study. (375)
- g. Theory is needed of free pressure waves in the atmosphere; extension of the theory of Pekeris (1948) to other models, considering the most recent data on temperature in the stratosphere and in the ionosphere. (375)
- h. Properties need to be determined of sound waves refracted at levels near 100 km (Cox, 1949) and of free pressure waves (Guttenberg, 1942). (375)
- i. Natural pressure waves in the atmosphere in various latitudes, on islands, near coasts, and far inland (including use of tripartite stations with base lengths of about 1/4 of the wavelength of the waves to be studied, and causes of such waves (Guttenberg and Beneoff, 1941) and their possible use in weather forecasting needs study. (375)

G. COSMICAL METEOROLOGY

1. Solar Energy Variations as a Possible Cause of Anomalous Weather Changes (R. Craig and H. Willett)
 - a. An attempt should be made to investigate, independently of the Smithsonian Institution, the variations of the solar constant. (388)
 - b. Theoretical and physical meteorologists must give attention to the question of how impulses received in the upper atmosphere can affect the troposphere. (388)
 - c. The question on whether ultraviolet solar variability affects the weather needs to be resolved due to its great interest. (388)
 - d. The statistical study of day-to-day, week-to-week, and secular weather variations as related to solar variability should continue. (389)
2. The Atmospheres of the Other Planets (S. Hess and H. Panofsky)
 - a. For Venus, the outstanding meteorological problems are: 1) determination of the nature of the variable light and dark bands observed in the ultraviolet, and 2) determination of the cause of the variability of the emission from the planet's carbon dioxide at 10 μ . (397)
 - b. For Mars, one would like to see a verification and extension of the work on the temperature field and general circulation. (397)
 - c. For Mars, there is also a need for further observations of such fundamental quantities as the atmospheric pressure, the amount of water vapor, the height and composition of the blue haze layer, and the value of the nocturnal temperatures. (397)
 - d. For Jupiter, a study of the latitudinal variation of ammonia and methane absorption is needed. (397)
 - e. The correlation between the motion of the Red Spot on Jupiter and the zonal index on the Earth should be verified on observations since 1939. (397)

- f. For Saturn, similar investigations might be suggested, especially as far as the evaluation of the limb darkening is concerned. (397)

H. DYNAMICS OF THE ATMOSPHERE

1. The Perturbation Equations in Meteorology (B. Haurwitz)

- a. A quantitative study of developing perturbations beyond their nascent linear stages appears indispensable for the future development of the perturbation theory. This should contribute significantly to the problem of: 1) the stability or instability of a given atmospheric flow pattern, 2) how an unstable flow pattern can develop, and 3) the fluid motions caused by these perturbations. (419)
- b. The omission of terms in the original system of equations may lead to erroneous equations when the necessary eliminations are carried out. Much work, therefore, remains to be done in the study of progressively more realistic models (419)
- c. Little work has been done so far to extend the perturbation theory to viscous fluids. (419)
- d. More attention needs to be given to the problem of heat conduction and radiation in perturbation motions. (419)

2. The Solution of Nonlinear Meteorological Problems by the Method of Characteristics (J. Freeman)

- a. The effect of the Coriolis force in flow under an inversion needs to be studied. (432)
- b. The characteristics of a circular vortex and the "rings" of a hurricane need to be studied. (432)
- c. A fruitful field of investigation is vortex sheets and their role in bringing about frontogenesis. (432)
- d. Further study is needed on the "expansion-wave storm" where an expansion wave moving from the west followed by a compression wave and subsequent pressure jump on the inversion north of the quasi-stationary front is considered. (432)
- e. Further study is also needed on blocking waves in a planetary jet stream using the method of characteristics. (432)

3. Hydrodynamic Instability (J. Van Mieghem)

- a. The problem of atmospheric perturbations is so difficult that drastic assumptions are inevitable if one really wishes to undertake its solution. (445)
- b. It is particularly with reference to the importance of hydrodynamic instability in the formation of cyclone circulation that new synoptic studies, in greater number and on a larger scale, appear to be desirable. (452)

4. Stability Properties of Large-Scale Atmospheric Disturbances (R. Fjrtoft)

- a. It is not unlikely that the study of an atmosphere where typical barotropic and baroclinic effects are operating in full generality may contribute considerably to a further understanding of the behavior of the atmosphere. (463)

5. The Quantitative Theory of Cyclone Development (E. Eady)

- a. We need to compute the further development of cyclones when the perturbations are no longer small. (469)
- b. Understanding the precise significance of our solutions is a necessity. (469)
- c. We need to develop the statistical theory of cyclone development. (469)

6. Dynamic Forecasting by Numerical Processes (J. Charney)

- a. Once the physical problem of determining the equations of motion and boundary conditions have been solved, there arises the purely mathematical problem of approximating the solution of the continuous equations by finite-difference methods. (477)
- b. A great deal of research remains to be done before enough is known about the turbulent transfer of momentum and heat to permit the assigning of even rough values to the eddy coefficients of viscosity and heat condition. (482)

7. Energy Equations (J. Miller)

The general energy equations cannot be applied successfully to the real atmosphere until more is known about the eddy term. (491)

- a. The energy equations, being in differential form, represent relationship between instantaneous rates, but they tell nothing about the relative magnitudes of the various rates of work, flux, and charges of energy. The solution to the problem lies in the initial and boundary conditions. (491)
- b. There should be more attempts to formulate the necessary guiding principals to permit a complete solution to problems using the energy equations through studies of atmosphere energy. (491)

8. Atmosphere Turbulence and Diffusion (O. Sutton)

- a. No general method has yet been evolved for expressing the Reynolds stresses in terms of the velocity components and their spatial derivatives by exact analysis. (493)
- b. Systematic simultaneous records of both temperature gradient and radiative flux are needed of the lower atmosphere. (498)
- c. There remains much to be learned concerning the structure of turbulence near the ground. (499)

- d. There is very little information on the distribution of energy among the fluctuations and a complete picture of the eddy spectrum is not yet available. (499)
 - e. The only direct measurement yet made of the Reynolds stress in the atmosphere does not support the theoretical deduction of invariability with height, and the discrepancy has still to be explained. (500)
 - f. A complete investigation of the drag of the surface or of the transfer of momentum in large temperature gradients has not yet been made. (500)
 - g. Much remains to be explained concerning the details of large cellular convective motion. (503)
 - h. The problem of turbulence in the upper atmosphere has recently arisen in a acute form in relation to the design of large aircraft. (503)
 - i. The applicability of the Reynolds process of averaging in dealing with major atmospheric motions is still uncertain. (503)
 - j. The fundamental problem for the mathematical physicist is to find means whereby the properties of continuously generated clouds in conditions of small temperature gradients can be derived from measurements of the relevant meteorological factors, such as the profile of mean velocity, gustiness and temperature gradient. (503)
 - k. There is need for a detailed pure mathematical examination of the type of equations applicable to three-dimensional problems (504)
 - l. There is a need in micrometeorology for instruments whose accuracy approaches that attained in the laboratory yet are sufficiently robust to be used in the open atmosphere. (506)
 - m. There is, in particular, a need to examine both practically and theoretically the basic assumptions of the various theories. (506)
 - n. The exact value of the critical Richardson number (if indeed it exists) is one of the most open in meteorology. (506)
 - o. The characteristic meteorological problem, that of diffusion in large density gradients, is still unsolved. (506)
 - p. The solution of the problem of the transfer of heat from the ground to air, or vice versa, is still far from complete. (507)
 - q. A satisfactory theory of diffusion in large inversions and large lapse rates has yet to emerge and should receive urgent attention from meteorologists. (507)
9. Atmospheric Tides and Oscillations (S. Chapman)
- a. The ionosphere with its several layers each needs separate examination as regards the solar and lunar daily changes in its height, electron density, and other properties. (527)
 - b. The components of cosmic radiation with different penetrative powers and daily magnetic variations deserve independent treatment relative to oscillations in the ionosphere. (527)

- c. The daily variations of ground level pressure still need further study, and an improved treatment of the solar daily variation of air temperature is required to elucidate the thermal part of the solar half-daily tide. (527)
 - d. Study of the lunar tidal winds has only begun, and there is much scope for study of the periodic winds associated with both the solar and the lunar daily atmospheric oscillations. (528)
 - e. It is desirable that the search be extended to the minor periodic components, such as the lunar diurnal tide, and the components associated with the changing distance of the moon. (528)
 - f. The existing theory of atmospheric tides and oscillations will need to be revised as our knowledge of the temperature-height distribution in the upper atmosphere advances. (528)
 - g. The regional anomalies in the distribution of the lunar tide, as shown by the barometric variations, require quantitative explanation. (528)
10. Application of the Thermodynamics of Open Systems to Meteorology (J. Van Mieghem)
- a. A thermodynamic theory of microturbulence remains to be worked out. (527)
 - b. New investigations, both theoretical and synoptic, into the sources and the flux of momentum, of energy in its various forms (Van Mieghem, 1950) appear desirable. (537)

I. THE GENERAL CIRCULATION

1. The Physical Basis for the General Circulation (V. Starr)

- a. No satisfactory rational explanation exists for the large belts of westerly winds in the temperature latitudes of each hemisphere. (541)
- b. We have not fathomed the profundity of our subject, let alone solved the fundamental problems. (544)
- c. Further exploration is needed of the essential properties of the global circulation, as we know it from observations, with regard to such dynamic quantities as angular momentum vorticity, kinetic energy, heat energy, geopotential energy, and latent heat. (544)
- d. What are the cause of the vagaries in the behavior of the general circulation? (546)
- e. Why does the average state of the general circulation not persist without pronounced departures? (547)
- f. The suggestion by Willett (1948) that the seat of the variation (of the general circulation) could perhaps be found in the variations in solar output, and hence the heating of the atmosphere, deserves study. (547)
- g. We need quantitative estimates of the flow of heat, of kinetic energy, of momentum, etc., for the mean state and also when consideration is given to synoptic and seasonal variations. (548)

- h. There is a need for a more complete and systematic empirical description of the basic physical processes involved in the general circulation. (548)
2. Observational Studies of General Circulation Patterns (J. Namias and P. Clapp)
 - a. At present there is no completely quantitative utilization of theoretical findings in forecasting. (566)
 - b. A need exists for a better understanding of atmospheric processes through more intensive studies of existing data and improvement in observational techniques. (566)
 - c. The historical Northern Hemisphere map project for the war years 1939 through 1945 needs to be completed. (566)
 - d. Observational (including winds and moisture taken at high atmospheric levels) networks should be chosen so that there is a more even distribution over the globe. (566)
 3. Applications of Energy Principles to the General Circulation (V. Starr)
 - a. Our observational information concerning the problem posed by the global energy balance is very sketchy and incomplete. (573)
 - b. A more satisfactory appraisal is needed for the magnitude of the terms of the equation for the total net rate of heating. (574)

J. MECHANICS OF PRESSURE SYSTEMS

1. Extratropical Cyclones (J. Bjerknes)
 - a. There is still a wide gap to be bridged between the existing theory of dynamic instability and the applications called for in daily synoptic practice. (597)
 - b. Synopticians need the criteria of dynamic instability for large-scale atmospheric currents which are nonzonal and nonpermanent. (598)
2. The Aerology of Extratropical Disturbances (E. Palmén)
 - a. There still is no complete theory of frontogenesis which considers the entire dynamics of the general circulation. (618)
 - b. The question of the role of extratropical cyclones in the complex problem of the general circulation is of primary importance. (618)
 - c. The fundamental cyclone problem would be solved in principle if one could find the causes and mechanism of the breakdown of the zonal current into a more irregular form of movement. (618)
 - d. Given the complexity of the cyclone problem, it does not seem likely that any satisfactory theoretical solution can be achieved in the near future. (619)
 - e. Further detailed synoptic investigations of selected types of disturbances will improve our knowledge and understanding of the dynamics of the atmosphere. (619)

- f. The time difference between radiosonde observations (now twelve hours for most locations) is too large to permit a satisfactory determination of the time derivatives. Special synoptic investigation with severe stations operating on time intervals of two to three hours would, therefore, be extremely valuable. (619)

3. Anticyclones (H. Wexler)

- a. The central problem concerning anticyclones is the explanation of the warm, deep "dynamic" anticyclone. (628)
- b. Complete explanations of the "piling-up" of air associated with warm, deep dynamic anticyclones and its counterpart, the removal of air which characterizes the cyclone, are still lacking. (628)
- c. The influence of the configuration of the westerlies and surface conditions on the cause and location of deep anticyclones is not fully known. (628)
- d. The role of advection in the upper troposphere in instituting or strengthening anticyclogenesis requires clarification. (628)
- e. Whether changes in the height and temperature of the tropopause precede, accompany, or follow anticyclogenesis deserves further study. (628)
- f. The existence and location of the high-level anticyclones south of the westerlies should be examined, especially in relation to tropical rainfall patterns. (628)

4. Mechanism of Pressure Change (J. Austin)

- a. Theoretical analysis of the development of divergence and vertical-motion fields with pressure changes appears to be inadequate. (637)
- b. There are gaps in our knowledge concerning the manner in which divergence and vertical-motion fields develop and move with migratory pressure systems. Much of the empirical information is based upon twelve-hour changes and it is possible that such data give an incorrect impression of the motion in areas of pressure change. (637)
- c. The direct influence of nonadiabatic temperature changes or pressure changes requires further consideration. (637)
- d. The details of horizontal advection require more investigation in order to ascertain whether advection should be considered a cause or an effect of pressure change. (637)
- e. The complexity of the temperature field in the vicinity of the tropopause warrants further consideration of the stability of this field. (637)
- f. The influence of surface friction must be further investigated. (637)
- g. It is necessary to develop a thermal model which gives a pressure change in a quiescent region, followed by a moving pressure-change field with its associated changes at various levels, and then the end stage of a cold cyclone or warm anticyclone. (637)

- h. A preliminary step toward an explanation of pressure change is an accurate description of all features of wind, pressure, and temperature fields in the vicinity of pressure changes. (637)
 - i. The pressure tendency equations make it possible to check the internal consistency of such pictures. In connection with this important aspect of pressure-change research the author suggests the desirability of utilizing to a greater degree other relationships which may be derived from the equations of motion. (637)
5. Large-Scale Vertical Velocity and Divergence (H. Panofsky)
- a. It is desirable in the future to study forecasting techniques based on vertical velocities. (646)
 - b. The vorticity equation (written where we neglect solenoidal fields, friction, and terms depending on the horizontal variation of vertical velocity) should be applied to the forecast of changes of vorticity from observed divergence. (646)
 - c. Studies in regions other than the middle latitudes of the Northern Hemisphere are desirable in order to determine whether there exists a general relation between vertical and meridional motion or vertical velocity and advection. (646)
 - d. Moreover, a study of the relation between vertical velocities, divergence, and weather is desirable in other sections of the globe. (646)
6. The Instability Line (J. Fuls)
- a. The collection of more adequate detailed observational data and the analysis of existing data is needed. (652)
 - b. More observational data for upper levels in the immediate vicinity of tornadoes is especially needed. (652)
 - c. A more adequate theory of the mechanics of the tornado would be an important step toward understanding the stability line. (652)
 - d. Better basic knowledge of the instability line would aid in the interpretation of synoptic data and their use in developing better forecasting methods. (652)
 - e. It is also important to develop criteria for determining the individual characteristics of each stability line and means of forecasting the dissipation of the line. (652)

K. LOCAL CIRCULATION

1. Local Winds (F. Defant)

- a. Further intensive investigation of the vertical structure of land and sea breezes on especially suitable coasts by means of continuous aerological measurements over land and water at various distances from the shore would be most desirable. As regards the theoretical aspects, the problem appears adequately solved. (670)

- b. Accurate aerological cross sections along favorably situated slopes up to the ridge are still needed. (670)
- c. Systematic upper-air soundings should be carried out in a particularly favorable valley location from its deepest recesses out into the plains. Special attention should be given here to the interrelation between the slope wind and the valley wind. Such investigations should cover the entire cross section of the valley up to the ridges of the flanking mountain chains. (670)
- d. The cell circulation for an inclined slope and the connection of the slope-wind circulation with the system of the mountain and valley winds still constitute a theoretical problem. (671)
- e. As an extension of the work of W. Schmidt (1930), a comprehensive monograph on the occurrence of the foehn in all areas of the world, with special emphasis on its climatic importance, is needed. (671)
- f. As far as the foehn theory is concerned, its thermodynamic aspects appear to be completely explained. The dynamic side of the problem, which is a purely hydrodynamic problem, can be advanced only by special aerological investigations in the different mountain ranges of the world. (671)
- g. Special attention should be paid to the problem of wave formation in the lee of the range. (671)

2. Tornadoes and Related Phenomena (E. Brooks)

- a. What is lacking is the application of satisfactory hydrodynamical theories to the frictional vortices of tornadoes, dust devils, and waterspouts. (679)
- b. Suggested items for study are: 1) the outflow aloft (method of removal and destination of removed air), 2) the formation by action of hail, and 3) the sense of rotation, as examples of explaining facts, checking proposed theories, and verifying accepted ideas, respectively. (679)
- c. Many more surface and upper-air observations are needed and meteorological data ought to be gathered over micronetworks which could detect the development of a small secondary cyclone and would accurately locate squalls, thunderstorms and hail showers with respect to the tornado. (679)
- d. Careful surveys should be made of the damage after a tornado occurs to determine winds and atmospheric pressure drops. (679)
- e. A standardized questionnaire should be published in local newspapers with a request for replies and copies of local photographs obtained for analysis. (679)
- f. A more complete knowledge of the small-scale circumstances attending tornadoes is needed for the understanding of the nature and causes of tornadoes. (679)

3. Thunderstorms (H. Byers)

- a. No rational picture of a thunderstorm cell with the downdraft decreasing downward has been devised. (691)

- b. It is not known to what extent entrainment involves lateral mixing. (691)
- c. Further measurements are also needed concerning the tendency toward desiccation of the downdraft air, as indicated by the "humidity dip" at the ground in the rain core. (691)
- d. Additional observations should be made on thunderstorms in arid regions, especially in those cases where the condensation level is very high and the rain may sometimes evaporate before reaching the ground. (691)
- e. The problem of hail has not been solved in relation to thunderstorms. (691)
- f. The problem of hail in the generation of thunderstorm electricity is a critical one. In spite of the nearly 200 years that have elapsed since Benjamin Franklin discovered that lightning was a form of electricity, we still are not sure what causes it. (691)
- g. The squall line and tornadoes in relation to thunderstorms are a wide-open field for investigation. (691)
- h. The dynamics of the pre-cold-front squall line—whether it is a hydraulic jump phenomenon as emphasized by Tepper (1950) or has other special characteristics—need further investigation. (691)
- i. Is there some predisposition for extreme convection in the atmosphere to occur in lines? If so, why? (692)
- j. At this writing, computations of the water budget and the energy budget reveal problems of a fundamental nature. One finding is that under average conditions only 10 percent of the total water involved in a thunderstorm reaches the ground as rain. (692)
- k. Computations of the energy budget of the thunderstorm show that ideas about thermal instability and its prognostic value not only need to be revised but may have to be abandoned altogether. (692)
- l. Two factors having no very direct connection with the thermal stability of the atmosphere appear to be important for the formation of thunderstorms: 1) the occurrence of local regions of convergence, often too small in area to be detected by the existing network of upper-wind stations, and 2) the absence of low moisture in the vicinity of the 315K potential-temperature surface. Why other potential-temperature surfaces are not very critical in American summer conditions is not understood. (692)
- m. Studies point to the desirability of undertaking further investigations of isentropic or similar charts and of using a net of upper-wind stations with a 50-mile or, at most, 100-mile mesh to obtain usable divergence-convergence charts. (692)
- n. Finally, one is not sure why thunderstorms should ever occur. The atmosphere seems to be able to take care of the vertical heat exchange without such violent manifestations. Since thermal instability seems to be a necessary but not a sufficient condition for thunderstorms, ordinary cumulus convection appears to be capable of taking care of the situation. As the thermal instability increases, why can't the necessary overturning be accomplished by a great number of fast-circulating cumulus of small diameter rather than a few big thunderstorms which never seem to cover more than about 50 percent of an area of about 55,000 square miles such as shown on radar at ranges between 20 and 50 miles? (692)

4. Cumulus Convection and Entrainment (J. Austin)

- a. No satisfactory procedure has been offered whereby the degree of entrainment and mixing may be estimated and recent analyses of entrainment have failed to take into consideration the disturbed state of the environment. (700)
- b. More theoretical research is clearly indicated if it is desired to know the physical properties of the cloud at a given time. (700)
- c. One feature of cumulus growth which requires more consideration is the significance of the surface heating. (700)
- d. It appears likely that no major progress will be made with the forecast problem of cumulus convection until more knowledge is gained of the mechanics of cloud growth. (671)

L. OBSERVATIONS AND ANALYSIS

1. World Weather Network (A. Spilhaus)

- a. The principal lines along which further work should proceed in order to fill out the world network may be summarized as follows:
 - 1) The development of automatic stations for land and ocean, tropical and polar use.
 - 2) The filling out of the land station network in tropical areas.
 - 3) The establishment of manned or automatic surface stations on suitable islands and reefs.
 - 4) The establishment of upper-air stations on selected islands and reefs. These would be manned, but, at the same time, it would be desirable to initiate research on indirect methods of atmospheric sounding without flight equipment, which would lend themselves ultimately to automatic operation.
 - 5) The development of buoys, which could be anchored in deep water, to carry manned stations or automatic stations for remote oceanic points.
 - 6) The development of methods of getting in and out of arctic and antarctic areas and of maintaining manned stations and automatic stations in those regions. (709)

2. Models and Techniques of Synoptic Representation (J. Bellamy)

- a. The use of inadequate parameters to describe synoptic observations can be eliminated by the use of parameters defined in terms of deviations from standard atmospheric conditions. (713)
- b. The use of inadequate methods of plotting parameters on maps or charts can be eliminated by the use of isometric graphical representation of the observations. (713)
- c. The use of inadequate communication systems can be eliminated by the use of a direct-writer type of communication system. (713)

3. Meteorological Analysis in the Middle Latitudes (V. Oliver and M. Oliver)

- a. In various specific contexts in the discussion of analytical techniques we have mentioned the value of the use of color in augmenting the clarity of analyses. The psychological effect of color and its use as an aid to analysis should in the future receive the attention it warrants. (726)
- b. Another neglected problem is that of the ideal arrangement for an analysis center or forecast station. As far as the authors can discover, the results of comprehensive studies of this subject have not been incorporated into actual practice. (726)
- c. One of these fundamental barriers to rapid advancement in the field of meteorology as a whole is the confusion occasioned by the plethora of theories and operational practices, attending the sudden multiplication of reliable meteorological instruments, which has presented for the scrutiny of the forecaster an entirely new and unprecedented multiplicity of data. (726)
- d. The other basic obstacle is the enigma of the processes involved in the general circulation of the atmosphere. Once a valid theory of this general circulation has crystallized, order should begin to appear in the present chaos of our secondary meteorological theories. However, until such time as this is accomplished, it behooves those of us concerned with analysis to follow up whatever lines of research seem promising, searching through meteorological theory for effective applications to analysis and seeking to better our analytical techniques through experimentation and critical discussions participated in by meteorologists all over the world. (726)

M. WEATHER FORECASTING

1. The Forecast Problem (H. Willett)

- a. The basic problem of forecasting research is to derive some quantitative physical model of the general circulation which fits the statistical and synoptic facts of weather observation. (744)
- b. Many years of intensive study of regional weather patterns have failed to evolve either a physical model or a theory of cyclogenesis and anticyclogenesis (pressure changes) of any real practical value in forecasting regional changes of the synoptic weather patterns. Gross inadequacy of world-wide observational synoptic data has prohibited any corresponding study of the general circulation in its entirety. (744)
- c. The closest possible cooperation should be established between the theoretical and the synoptic-statistical meteorologists such that all theory and hypotheses may be influenced and rigidly checked by the observational facts. The primary objectives include: 1) the determination of the primary energy sources and sinks in the atmosphere, as well as of the energy transformations and transportation from source to sink, 2) the establishment of the entire dynamics and thermodynamics of the operation of the general circulation as a whole between energy source and energy sink, and an understanding of the mechanics of interaction between the zonal and cellular branches of the general circulation, and 3) the determination of the physical nature of the irregularly variable solar activity, to its direct effects in the higher atmosphere, and to the transmission of all such direct or indirect effects to the lower atmosphere, notably to the troposphere in the tropics, where the influence of the irregular solar activity on the weather is most directly in evidence. (745)

- d. The establishment is needed of a well-integrated world-wide system of uniformly distributed synoptically reporting stations, operating under the direct control and support of a strong international meteorological organization. (745)
- e. The development is needed for more effective synoptic tools or techniques for the presentation and analysis of synoptic weather observations on a world-wide scale. (745)
- f. One central international meteorological research center, under competent direction, should be established where leading meteorologists of all nationalities would be enabled to work under conditions of complete cooperation and exchange of ideas, with a maximum of readily available synoptic data and the necessary amount of clerical assistance. (745)

2. Short-Range Weather Forecasting (G. Dunn)

- a. Continued intensive research on the general circulation should have the highest priority. (763)
- b. Of paramount importance to short-, medium-, and long-range forecasting are the causes of the departures of the centers of action and mean troughs and ridges from their normal location and intensity—anomalies which may persist for a matter of months. (763)
- c. Of equal importance are the causes of the variations of the zonal indices, which in turn permit, at times, excessive zonal or meridional flow; it is likewise desirable to learn how these variations can be forecast. (763)
- d. This problem of qualitative and quantitative forecasting of precipitation is urgent and includes:
 - 1) Determining when and where precipitation will break out in a previously dry trough.
 - 2) Accurately timing the beginning of precipitation 12-24 hr in advance.
 - 3) Forecasting the nocturnal type of thunderstorm.
 - 4) The degree of concentration of the convective afternoon thundershower.
 - 5) The development of "bursts" of rainfall, instability lines (squall lines), and other zones of convergence.
 - 6) Correlation of precipitation with upper-air patterns and the direction and movement of lows, and development of methods of forecasting the great variation in warmer-sector precipitation.
 - 7) Investigation of the whole problem of summer-time precipitation, the causes of most of which are obscure. It is suggested that further relationships between showers and convective instability be developed to reduce the forecasting of showers to some practical numerical basis. (763)
- e. The causes of deepening and filling of pressure systems and the associated problem of wave development needs further research. (764)

- f. Less complex methods of employing acceleration and deceleration factors in forecasting the speed and direction of movement of highs, lows, and fronts are desired. (764)
 - g. Research on the treatment of cold upper-air lows; their formation, movement, and dissipation is needed. (764)
 - h. Bringing the historical weather map series up to date including 700- and 500-mb charts, is needed. (764)
 - i. Development of instruments which could measure vertical motions and changes in moisture and stability aloft is needed. (764)
3. A Procedure of Short-Range Weather Forecasting (R. Bundgaard)
- a. The author states that the practical procedure of short-range weather forecasting is simply the extrapolation, in a partly geometrical way, of a sequential weather situation and the extrapolation process, therefore, must also take physical considerations into account. Although not stated as a need, it would seem to follow that the availability of observational data with higher temporal and spatial resolution is also needed to improve the accuracy of short-range forecasts. (766)
 - b. Owing to a sparse network of observing stations, the position of disturbances have been analyzed inaccurately and the extrapolation of fast-running disturbances result in the so-called "weather surprises." (769)
 - c. Since no rigid set of tropospheric models exists, weather-map prognosis should not stiffen into a series of routine mechanical procedures. (770)
4. Objective Weather Forecasting (R. Allen and E. Vernon)
- a. The basic problems which are encountered in common with any other method of forecasting are a lack of understanding of the physical processes in the atmosphere and an inability to apply to practical problems such knowledge as now exists. (800)
 - b. Further progress could be expedited if a closer working relationship could be established between theoreticians and forecasters having an interest in the development of objective methods. (800)
 - c. Claims have sometimes been made that the objective forecasting methods are more accurate when station data rather than values interpolated from analyzed maps are used. This subject needs more investigation, for if the claims are valid, it follows that administrators should be more slow to move or to discontinue stations, and further that much of the emphasis on centralized, accurate analysis is misplaced. (800)
 - d. Graphical techniques such as the scatter-diagram technique used in searching for and testing relationships are unsatisfactory in spite of their success. More rigorous methods are needed, although it must be noted that difficulties seem to arise only when scatter diagrams are analyzed with too few data, or when there is no rational physical model underlying the selection of variables and the pattern of isograms drawn on the scatter diagram. (801)
 - e. It can be recommended that more forecasters attempt investigations of their own local forecasting problems. (801)

5. General Aspects of Extended-Range Forecasting (J. Namias)

- a. The problem of extended-range forecasting may be looked upon as the ultimate test of a complete theory of the general circulation. (812)
- b. Avenues of improvement of knowledge of the general circulation are directly applicable to the subject of improvement in extended-range forecasting. (812)
- c. Meteorologists the world over would do well to improve the position of extended-range forecasting by consolidating their gains of the past score of years. (812)
- d. Along this line, it would be desirable for those engaged in forecasting practice or research to make a greater effort to study and apply methods developed in other countries and to relate them to locally practiced techniques. (812)
- e. A highly practical problem is the need for a better method of representation of the tremendous wealth of data apparently necessary to make long-range forecasts. (812)
- f. Perhaps a healthier state of cooperation more conducive to progress could be developed between the so-called dynamic meteorologists and the practicing forecasters and empirical researchers. (812)

6. Extended-Range Weather Forecasting (F. Baur)

- a. The first basic problem of macrometeorology is whether or not a real "Grosswetter" exists at all. (814)
- b. What are the governing complexes comprising the variable conditions which produce variations in the meteorological elements from year to year? Are they of terrestrial or extra-terrestrial origin? (815)
- c. The question regarding the existence of periods other than the well-known daily and annual periods of weather phenomena is of great importance to extended-range weather forecasting. (816)
- d. The cause for the excitation of the Indian-Pacific temperature-pressure oscillation has not yet been determined. (817)
- e. The persistence and repetition tendencies of "Grosswetterlogen" should be subject to investigation in which statistics and synoptics supplement each other. (817)
- f. No one has ever proved in a single case to date that during or after a given arrangement of the moon or the planets any weather phenomenon occurred more frequently or less frequently than would have been expected from chance. (819)
- g. Fluctuations in the solar radiation represent complexes of conditions that govern the cause of the large-scale weather, therefore, an intensive promotion of solar physics is one of the prime prerequisites for progress in long-range weather forecasting. (822)

- h. Further investigations are needed to establish the relative frequency with which a strong meridional circulation on both sides of a steering center in the upper troposphere is associated with an intensified zonal circulation at a relatively large distance from this steering center. (830)
 - i. In order to develop circulation methods so that they can be used as a basis for reliable extended forecasts; a transition is necessary from the statistics of averages, now predominantly in use, to statistics of selected cases which take into account especially the physical processes, and the special characteristics of the particular case. (831)
 - j. Forecasts for more than five days are not impossible on a synoptic basis. The multitude of all possible developments no longer permits consideration of the development in all physical details. Here, statistics must be employed if we are to make statements about the future. However, two prerequisites must be fulfilled: 1) the choice of statistical methods must be guided by a physical formulation of the problems and by physical considerations, and 2) long-range forecasts should be given, at least publicly, only if better-than-chance statistical relationships are obtained to ensure the success of the forecast with a probability of over 92 percent. (831)
7. Extended-Range Forecasting by Weather Types (R. Elliott)
- a. Study of the long-period interaction between broad-scale circulation features in different parts of the Northern Hemisphere and, for that matter, over the whole world is needed. This, it would appear, involves the modes of energy dispersion. A joint theoretical and synoptic attack is in order. (840)
 - b. A thorough study is needed of the radiational properties of the earth and its atmosphere and the study of the effects of variations in solar output upon atmospheric motions. Meteorological events, seemingly inexplicable from the viewpoint of a closed system consisting of the atmosphere and the earth, are continually occurring and require a systematic investigation of extraterrestrial effects. (840)
8. Verification of Weather Forecasts (G. Brier and R. Allen)
- a. One of the most promising fields of study is that of setting up realistic problems to be solved and selecting scores which would furnish the desired information. Such studies might profitably be conducted in collaboration with administrators who need to select or rank forecasters; with economists or business advisors who need to know the effect of weather on operations and who are in the best position to determine what characteristic of the forecasts is related to profit and loss factors, or with meteorologists who know what characteristic of the forecast is useful for verifying scientific hypotheses. (847)
 - b. On the scientific side of verification, the relation of forecast error to measures of forecast "difficulty" needs further investigation. (847)
 - c. Investigations regarding the effect of verification systems on the forecaster are needed since very little concrete evidence on this point is available. In this connection the use of probability statements in forecasting needs to be explored in more detail, for if such statements can be verified without influencing the forecaster in any undesirable way, an important objection to verification is removed. (847)

- d. It has been assumed that errors of observation are unimportant in practical verification. This is not always the case, and further investigation of the effect of such errors is needed. (847)

9. Application of Statistical Methods to Weather Forecasting (G. Wadsworth)

- a. The future of meteorology depends decisively upon an enlightened and energetic use of statistical methods. (850)
- b. A reevaluation of the whole method of presenting the climatology of various localities and the individual behavior of climate during reasonably short periods of time at a particular locality might do much to increase our knowledge concerning the general behavior of the circulation. (853)
- c. In the light of past experience in forecasting by statistical methods, it is obvious that in order to progress much further it is going to be necessary to find a way of classifying the dynamics. (853)
- d. Parameters must be found that will adequately classify the static picture of the weather situation over a large area. Whatever parameters are used should maximize the discrimination between different synoptic situations. (853)
- e. Parameters should be found which actually classify the dynamic features of large areas. Having real physical significance, they would have some chance of being associated with both the static picture and the dynamic processes of the weather elements over an area. (853)
- f. The relationship between the static and dynamic properties of the parameters should be distinguishable so that it would be possible to go from one to the other and realize what is important from both points of view. (853)
- g. If the characteristics of the general flow could be determined by examining the dynamics of past situations and extrapolating them in order to obtain the dynamics of the present one in the correct manner, then it is entirely possible that the network theory of simple linear hypothesis would be sufficient to predict the individual weather at various localities by the use of an operator fitted to a correct dynamic model. (853)
- h. In order to determine why it is that the major centers of action have such variable dynamics from year to year, it may be desirable to examine more carefully variations in sea-surface temperature. Also, since about three-quarters of the world is ocean, perhaps too little thought has been given to these variations as potential sources of the fluctuations in the dynamics of the weather system. (854)
- i. It seems advisable that investigations utilizing the statistical approach be greatly increased so that more and more information will be available, thus clarifying the nature of the phenomenon with which we are dealing. (854)

N. TROPICAL METEOROLOGY

1. Tropical Meteorology (C. Palmer)

- a. There are literally not sufficient data to make a single reliable statistical generalization applicable to the upper levels. (863)

- b. The time is now ripe for a more intensive investigation of those parts of the tropics that show large seasonal variations in the meteorological elements. (873)
- c. The filling of the gaps in our observing network is an absolutely necessary (although not sufficient) condition of the solution of the long-range forecasting problem. (873)
- d. We need an extensive investigation of the necessary and sufficient conditions for the formation of rain in the tropics. (878)
- e. Theoretical knowledge of the factors affecting the lapse rates in clouds derived from entrainment studies, together with information on the path of the sonde with respect to the existing cloud masses, might do much to remove the perplexity that the present soundings sometimes cause. (878)
- f. The challenging research task exists of collecting, reducing, and studying the unique wartime tropical data before they become lost forever. (878)
- g. The prospect exists of new empirical discoveries in a field from which the major errors have just been cleared away — discoveries, moreover, that cannot fail to react on the theory of fronts and air masses in high latitudes. (878)
- h. A series of problems exists in perturbation theory, applicable to an atmospheric region which, more closely than any other on this earth, resembles the dynamic meteorologist's ideal: the homogeneous, horizontally moving, frictionless, and incompressible fluid. (878)

2. Equatorial Meteorology (A. Grimes)

- a. The day-to-day determination of the vertical structure of the air masses will not be possible until observations are available in greater quantity and with more precision. (882)
- b. The question of the existence or non-existence of true frontal discontinuities in the equatorial region is one of the most controversial issues of tropical meteorology. (882)
- c. The particular problem of finding dynamical equations applicable to the movements of air within the equatorial region is peculiar to the region. (883)
- d. It is clearly important to determine how much cross-isobar motion exists in the free air and whether there is, in fact, any wind in the absence of a pressure gradient (Crossley, 1946). (883)
- e. One of the major problems that remains to be tackled is how to allow for the effect of the diurnal and semi-diurnal variations of pressure which dominate the barograms of the equatorial region. (885)
- f. There appears to have been no prolonged investigation into the application of corrections for diurnal variations of pressure and weather on the synoptic chart. (885)

3. Tropical Cyclones (G. Dunn)

- a. Since tropical cyclones are relatively small, a denser network of observing stations is a prerequisite to further progress. (900)

- b. The original causative factors which change the normally very weak and transitory pressure and wind deformations in the trades and the intertropical convergence zone to unstable waves and from the latter to intense tropical storms are not fully known. (900)
- c. Practical techniques of adequately measuring and determining the slight differences in the moisture and stability of inflowing air and the establishment of criteria for limiting pressure gradients and wind shears in the developing tropical cyclone would provide valuable tools for the forecaster. (900)
- d. Although forecasters are using certain techniques based on steering at some arbitrary level or immediately above the storm circulation, further objective tests of these empirical rules are desirable. (900)
- e. Further systematic collection of all observational data from tropical cyclones for statistical and physical analysis is badly needed. (901)
- f. Further studies are required to determine the exact relationship between the computed cyclostrophic term of the gradient wind and the observed wind, as a function of wind direction, velocity, storm movement and other characteristics. More data on the actual pressure-gradient and wind-velocity relationships are needed. (901)
- g. Theories on the exact mechanics of evacuating air from the storm area are mainly deductive in nature, and data are insufficient to substantiate or disprove them. (901)
- h. A flight by Wexler (1945) into a tropical cyclone in a plane equipped with a radio altimeter indicated areas of convergence considerably at variance with the normal concept of convergence and divergence in the storm area. The accumulation of data to answer this question should not be difficult. Traverses should be made into storms at lower altitudes. (901)
- i. By means of planes or parachute radiosondes, more observational data, including rate of descending air, should be secured from the eye of the storm. (901)

4. Aerology of Tropical Storms (H. Riehl)

- a. A complete three-dimensional description of hurricanes, such as has been rendered for middle latitude cyclones, is as yet in the distant future. (902)
- b. The number of observations available for analysis and forecasting of tropical storms have always been notoriously scarce. (902)
- c. A good description of the state of the sky in surface observations still is hampered by the archaic code. (902)
- d. Rawins should replace pibals everywhere and night-time soundings should be continued and expanded. (903)
- e. Tropical analysis should be extended to high levels and latitudes. (903)
- f. Opinions differ widely as to the latitude at which the gradient-wind relation becomes useless. (903)

- g. Further descriptive and analytical discussion of the hurricane microstructure, as revealed by the precipitation bands which spiral cyclonically toward the center, is one of the more interesting topics that await the investigator. (905)
- h. Up to now, no one has calculated the total effect that storms can exert on the general circulation as a result of the upward transfer of heat. (906)
- i. A considerable advance could be gained through a serious attack on the connection between synoptic situation, distribution of convergence, and storm motion. (906)
- j. Our knowledge regarding the wind distribution within tropical storms and the dynamical laws that guide the air from the outskirts to the center of the cyclones is so deficient as to be deplorable. (906)
- k. No laboratory experiment has been carried out to determine whether "simple" vortices can be generated in air as in liquids. (906)
- l. None of the factors that can be responsible for the fact that the absolute angular momentum is not conserved in the air flowing toward the center of a tropical storm. (906)
- m. The absolute calms frequently observed or the variable diameter of eyes of tropical storms have not been explained. We also have no knowledge concerning the rate of vertical motion in the eye. (907)
- n. The need for accurate data stands out as the foremost requirement to advance research on the quantitative considerations for the maintenance of tropical storms. (907)
- o. The question of the upper outflow necessary to account for the observed surface pressure falls has not been answered (Brunt, 1939). (907)
- p. Under what circumstances will storms attain great intensity? (909)
- q. The future evidently must concern itself with further development of models that lead to cyclogenesis. (910)
- r. Studies are needed to determine which theoretical restrictions are immaterial for the forecast of motion of disturbances and which impose limitations. (911)
- s. The state of knowledge with respect to the many situations when recurvature hangs in the balance is unsatisfactory. (911)
- t. The internal forces within a storm cannot be measured at all at present. (911)
- u. More data is required if physical analysis of recurvature is to make much headway. (911)
- v. It is of greatest importance to forecast when large tropical storms, i.e., typhoons, will stagnate and when and how they will resume motion. In the whole field of hurricane research work, this topic has been left untouched more than any other. (912)
- w. The outstanding deficiency for future research is the lack of observations which is so keenly felt in all low-latitude work. (912)

- x. Detailed observational programs should be initiated for short periods in low latitudes during the hurricane season. (912)

O. POLAR METEOROLOGY

1. Antarctic Atmospheric Circulation (A. Court)

- a. The Antarctica's atmospheric circulation and its causes and effects are major gaps in current meteorological knowledge. (917)
- b. The relation between the hemispheric circulation and sea-ice conditions is a complex problem, but one of the most important in Antarctica's meteorology. (937)
- c. Sorely needed are a few year-round stations well in the interior of the continent. (937)
- d. Ozone concentrations must be measured throughout the year at several places, and air samples should be procured weekly at Antarctic bases, for later laboratory analysis, until the apparent oxygen deficiency is established or disproved. (937)
- e. Pressure surges can be sought in the more recent data to determine whether any benefits to forecasting can be obtained. (937)
- f. The anomalous post-midnight maximum of temperature on clear winter days requires explanation. (937)
- g. Further exploration of the continent is needed since the meteorologist must know the nature of the land (or ice) surface in order to understand the weather processes above it. (937)
- h. Expeditions which go to Antarctica should have meteorologists not only competent to obtain the needed observations under adverse conditions, but meteorologists who understand the problems which they are to help solve. (937)

2. Arctic Meteorology (H. Dorsey, Jr.)

- a. The existing situation is not entirely satisfactory with respect to availability of upper-air research data from the Eurasian Arctic. (950)
- b. Trends in current and planned meteorological research indicate that arctic soundings to altitudes well above 120,000 feet will be desirable when similar data from mid-latitude soundings to the ozonosphere are available. (950)
- c. Valuable contributions to existing information should result from studies on the connections and interactions between the state of the general circulation and semi-permanent systems, such as the Aleutian low, Icelandic low, Siberian high, polar high, and North American high. (950)
- d. Further studies are needed on the general circulation as regards that of the Arctic in relation to the tropospheric jet stream of the middle latitudes. (950)
- e. Another worthwhile objective for future investigations would be the comparatively unknown nature and extent of control imposed on the Arctic circulation by contrasts between continental and oceanic regions in the Arctic and in adjacent temperature areas. (950)

- f. Essential research is needed on the interactions between arctic and middle-latitude regions with respect to transfer of mass, momentum, angular momentum or vorticity, entropy, heat content and moisture content, and the propagation of horizontal oscillations or perturbations between different latitudinal zones. (950)
 - g. Solutions to the problems of heat balance and exchange by various causes, such as radiation, conduction, convection, advection, and latent heat changes are needed. (950)
3. Some Climatological Problems of the Arctic and Sub-Arctic (K. Hare)
- a. Research is needed on the ecological climatology of the Arctic and sub-Arctic. (953)
 - b. Additional research is needed on the climatological relation of sea ice. (953)
 - c. The modification of air masses over ice-covered seas is a fertile field for the dynamic meteorologist. (960)
 - d. The climatological background of the freeze-up of the open sea areas also requires investigation. (960)
 - e. The characteristic of coastal ice, especially in harbors, is another topic worthy of study by the climatologist. (961)
 - f. There is a need for further investigation of the Greenland icecap climate. (963)
 - g. It is imperative that the ablation cycle of the Greenland icecap be studied. (963)

P. CLIMATOLOGY

1. Climate – The Synthesis of Weather (C. Durst)

- a. The essential needs of climatology are in the first place a reorientation of the expression of climate and of the teaching of climate, and secondly, the explanation of climate as a physical and dynamical phenomenon. (967)
- b. There is a need for the synoptic worker and the climatologist to become accustomed to thinking in each other's terms. (974)
- c. There is a great need for detailed climatological literature, based on synoptic information, to be prepared for all parts of the world. (974)
- d. One of the most interesting problems is that of the process by which air flows into the anti-cyclone and the reason why it does so. A solution to this problem would throw light on the mechanism of climate. (974)
- e. In regard to sources we need to know more about the time taken for stagnant air to become homogeneous, and what influence radiation has on the establishment of homogeneity. (974)
- f. We should have information on the movements and the variations in intensity of sources from year to year and whether that intensity is associated with extraterrestrial phenomenon. (974)

2. Applied Climatology (H. Landsberg and W. Jacobs)

- a. One of the important questions is how can we interpolate between stations? (978)
- b. How long a period of records is needed to give an answer to a problem within an appropriate safety factor? Or, when does a frequency distribution become essentially stable, so that adding another year of observations would not add significantly to the result? (978)
- c. How far can comparative techniques be applied? (979)
- d. There is a need for the development of better statistical techniques specifically adopted to climatological problems. (979)
- e. There is a great need for the formulation of new criteria of the significance applicable to climate data. (979)
- f. There is need for new types of climatological observations many of which require new instrumental approaches. (989)
- g. There is a requirement for statistical solutions better adapted to the specific problem. (989)
- h. The classical methods of summarization and graphical presentation need radical overhauling in many respects. (989)
- i. We lack adequate methods for multidimensional representation of data. (989)
- j. A fruitful field for joint efforts by the synoptic meteorologist and the climatologist lies in the methods of air-mass climatology. (989)
- k. Research needs in the field of microclimatology have recently been presented by Braum and Court (1949). They may be summarized as follows: 1) standardization of microclimatic procedures and equipment, 2) more measurements on the vertical distribution of the usual climatic elements in the boundary layer over various forms of terrain and vegetation, 3) studies and causal understanding of the heat balance at the surface of the earth, 4) studies on the existence and extent of laminar layers near the surface, and 5) studies on the inter-relation of microclimatic factors and evaporation. (989)

3. Microclimatology (R. Geiger)

- a. There are many problems of microclimatological research which still await solution, and the practical applications of this research are almost unlimited. (1001)
- b. Instrumentation remains the basic problem of the investigation of microclimatology. Microclimatology also requires experimental areas well equipped with instruments, perhaps attached to observatories or universities. (1002)
- c. Future research should be accomplished in the largest possible variety of the macroclimates of the earth. Here lies a great future for basic research in microclimatology. (1002)

4. Geological and Historical Aspects of Climatic Change (C. Brooks)

- a. The greatest need at present is for a closer quantitative evaluation of climatic variations in geological time. (1017)
- b. More exhaustive quantitative study is needed of the effect of the various solar and topographic factors on climate, and particularly on temperature and on the circulation of the earth's atmosphere. (1017)
- c. It is only by the multiplication of such studies, both in space and time, that the fundamental problem of climatic variations can eventually be solved. (1018)

5. Climatic Implications of Glacier Research (R. Flint)

- a. Research on changes in glaciers should be pursued both more intensively and more extensively than hitherto. (1022)
- b. In the glaciologic field there is required a more nearly complete record of contemporary fluctuations of glaciers, so that after several decades curves prepared from annual observations will become available for comparison. (1022)
- c. In the geologic field the greatest need is for a better knowledge of the areas of glaciers at various times during the last 10,000 years. Specifically, what is required is the mapping and study of the abandoned younger end moraines of valley glaciers in selected mountain districts, and moraines and other deposits of the former ice sheet in northeastern North America, a region still little known. (1022)

6. Tree-Ring Indices of Rainfall, Temperature, and River Flow (E. Schulman)

- a. It is probable that the contributions of tree-ring analysis to meteorological and hydrological knowledge have only just begun to manifest. Advances will depend on two related developments: 1) the construction of growth indices for new areas, and 2) in areas already studied, the replacement or amplification of indices by others of greater fidelity to the limiting climatic variable. (1029)
- b. Potential sources of rainfall chronologies appear to exist in the mid-latitude Andes Mountains, the Mediterranean area, the northwest provinces of India, and elsewhere. (1029)
- c. The vast Siberian Arctic is, as far as is known, totally untouched as a source of temperature chronologies. (1029)
- d. The refinement of tree-ring data is primarily related to chronologies in semiarid regions. Even the most elaborate index of this type thus far available, that for the Colorado River Basin developed in 1945, is subject to considerable improvement. (1029)

Q. HYDROMETEOROLOGY

1. Hydrometeorology in the United States (R. Fletcher)

- a. The selection of storms hydrometeorologically analyzed for Depth-Duration-Area (DDA) values by the Corps of Engineers and the Weather Bureau should be greatly augmented.

For both theoretical and statistical research, there is need for such analyses of storms covering a wide variety of magnitudes, durations, areas, storm types, seasons, and locations. (1045)

- b. The use of punch-card techniques would facilitate extension of the work of Yarnell and other writers, as regards rainfall probabilities. Addition of data from large numbers of DDA-analyzed storms would eventually permit establishment of probabilities of occurrence of areal rainfall intensities. (1046)
- c. Statistical studies as to correlations between point and areal rainfall depths should be undertaken with the objective, among others, of determining the proper density for rain-gage networks. (1046)
- d. As suggested by Smith and Fletcher (1947), the use of radar for quantitative determination of precipitation intensities between observing stations may have practical possibilities. Development of electronic equipment to measure areal values of precipitation intensities would be of extreme value for both forecasting and planning. (1046)
- e. In theoretical hydrometeorology, the greatest need is for knowledge of the behavior of wind in space and time, over orographic and nonorographic terrain, in synoptic situations favorable for peak rainfall intensities. (1046)
- f. The equations of continuity and hydrostatics have been the principal theoretical relationships used in hydrometeorology. Exploration into the applicability of others, such as the equations of motion and of energy relationships, is needed. (1046)
- g. Results of research in the field of atmospheric turbulence can be turned to great practical use in hydrometeorology. Intimately connected with the theory of turbulence are the problems of snow melt, evaporation, behavior of wind over rugged terrain, and the aggregate behavior of raindrops in convective cloud currents. (1046)
- h. As far as the field of hydrometeorology is concerned, there are two main goals toward which research should be directed. The first is the development of improved theoretical equations relating rainfall depths, averaged over area and through duration, with measurable independent variables. The other is the establishment of physically reliable methods of maximizing the rainfall through maximization of the variables, in combination, to which it is related. (1046)

2. The Hydrologic Cycle and Its Relation to Meteorology – River Forecasting (R. Linsley)

- a. A technique for determining evaporation either by direct measurement of outgoing moisture or by computation from the energy balance, turbulent transfer, or other theory is urgently needed. (1049)
- b. A study of storm morphology with particular reference to the relation between maximum point and average depths of rainfall would also be of considerable value. (1050)
- c. Improvement of quantitative weather-forecasting techniques will materially aid the user forecaster. Needed is a detailed forecast extending from one to ten days in future, giving the amount, time of occurrence, and areal distribution of precipitation, and, if snow melt is involved, temperature. For a less detailed outlook for 30 to 90 days ahead, indicating in general terms the precipitation anomalies and temperature trends, is necessary. (1054)

R. MARINE METEOROLOGY

1. Large-Scale Aspects of Energy Transformation Over the Oceans (W. Jacobs)

- a. For the purpose of filling the gaps in our knowledge of the interrelations between oceanic energy transformation processes and fluctuations in the general circulations of the atmosphere and oceans, the short-term and nonperiodic aspects of the exchange of energy between ocean and atmosphere should be investigated. (1069)
- b. The seasonal and annual analyses of the exchange of sensible heat and water vapor between sea and atmosphere should be extended to the Southern Hemisphere as soon as the necessary humidity data become available. (1069)
- c. It is the author's opinion that a nonexhaustive list of the more important phases of the ocean-atmosphere energy relationships that need investigation should include:
 - 1) The determination of the nonperiodic and short-term variations in the energy exchange between ocean and atmosphere.
 - 2) The analysis of the seasonal and regional aspects of the radiative transfer of energy between sea surface and atmosphere.
 - 3) The determination of the surplus of solar energy stored in the oceans and transported by ocean currents.
 - 4) The analysis of the large-scale aspects of the transport of internal energy by the atmosphere over the oceans.
 - 5) The analysis of the large-scale aspects of the interconversion of heat and kinetic and gravitational potential energy of atmosphere and oceans. (1069)

2. Evaporation From the Oceans (H. Sverdrup)

- a. It is very desirable to obtain further direct measurements at sea of incoming radiation from sun and sky and of nocturnal radiation. (1080)
- b. Measurements of the reflectivity of the sea surface under different conditions are also needed, as well as further examination of the Bowen ratio (the ratio between heat losses from the sea surface by conduction and by evaporation). (1080)
- c. In order to advance our knowledge, it is necessary to carry out a large number of detailed measurements of conditions directly above the sea surface. (1080)
- d. Measurements of wind profiles are needed in order to examine the validity of the concept that at low wind velocities the sea surface is hydrodynamically smooth. (1080)
- e. Measurements are needed of humidity in order to examine the validity of the logarithmic law for the decrease of water vapor with height. (1080)
- f. Measurements of temperature are needed in order to establish the stability under which the observations are made. (1080)

3. Forecasting Ocean Waves (W. Munk and R. Arthur)

- a. The derivation of the physical laws governing the growth of the component wave trains under wind action remains the outstanding theoretical problem in the development of a method for forecasting the wave spectrum. (1088)
- b. The problem of forecasting the transformation of the swell traveling through the region of decay also resolves itself into the problem of forecasting the change in the spectrum of the swell. Further study is indicated. (1088)
- c. Among the more important practical problems is the prediction of waves and swell from a tropical storm. The rules of thumb which have been established do not in all cases lead to adequate forecasts. (1088)

4. Ocean Waves as a Meteorological Tool (W. Munk)

- a. Of particular importance is a better understanding of the decay of swell traveling through an area of calm or cross winds. (1099)
- b. Development and standardization of suitable recording and analyzing equipment is urgently needed. The determination of wave direction is an essential requirement in making use of wave records for tracking storms. (1099)
- c. The storm surge method is at such an early stage of development that further work along instrumental and theoretical lines is required before it is possible to make any definite recommendations. (1099)
- d. A systematic exploration of the spectrum of ocean waves is likely to lead to surprising new developments (1099)

S. BIOLOGICAL AND CHEMICAL METEOROLOGY

1. Aerobiology (W. Jacobs)

- a. One of the most pressing needs in aerobiology research is the establishment of a standard list of "biological indicators" or "markers." (1105)
- b. Additional research on the possible (free) aerial dissemination of virus substances is needed. (1107)

2. Physical Aspects of Human Bioclimatology (K. Buettner)

- a. There is much left to be done in the study of the effects of strong winds on clothed bodies. More open-air studies can be expected to yield stress data, integrating the effects of heat and humidity. (1122)
- b. There is a lack of data on wind velocity near the ground, radiation, vapor pressure, and soil temperature. (1122)
- c. A simple recording ultraviolet radiation meter might further the use of sharply defined ultraviolet doses in climatotherapy. (1123)

- d. Detailed studies, especially of the dependency of air pollution on weather, would facilitate the protection of the community. (1123)
 - e. Generally, we urgently need physiological methods indicating small discomforts from weather and clinical methods for the detection of the slightest and earliest traces of the various illnesses referred to above. With such data available, a statistical correlation of meteorological and medical phenomena could become fruitful. (1123)
3. Some Problems of Atmospheric Chemistry (H. Cauer)
- a. The most important task in the development of chemical meteorology and climatology appears to the author to be the training of analytical chemists who study physical chemistry and physical meteorology. (1126)
 - b. Further development of methodology is needed. (1126)
 - c. When these developments are more or less completed, it will be possible to undertake a third major task, that of making many parallel investigations in micrometeorological as well as world-wide networks under the most varied atmospheric conditions and at various heights above the ground. (1126)
 - d. The overall development of a practical "applied atmospheric chemistry" is an undertaking which will require two or three research teams of not less than eight or nine scientists well schooled in analytical technical methods, equipped with first-class laboratory facilities, and working in collaboration. (1135)
 - e. Simultaneous serial observations of various interrelated chemical substances in the atmosphere are badly needed, but very small groups will not be in a position to undertake the work required. Complementary physical measurements, such as nuclei counts and the measurement of ultraviolet radiation, should be undertaken simultaneously. (1135)

T. ATMOSPHERIC POLLUTION

1. Atmospheric Pollution (W. Hewson)

- a. Standardization in methods of handling several aspects of the problem should be achieved at the earliest possible movement. In particular, standard instruments and procedures of evaluation should be evolved and adopted for use. (1154)
- b. There is also an urgent need to adopt a standard terminology to ensure precision in presenting and conveying information. (1154)
- c. The theoretical development of the subject should be promoted in every way possible. The development of basic turbulence theory is prerequisite for fundamental advance in the study of atmospheric diffusion, and must be fostered. (1154)
- d. The problem of diffusion of effluents in a city should be investigated intensively, since the pollution nuisance reaches the ultimate there. A program in which experiment and theory are both fully developed toward a common end is required. (1154)

- e. Micrometeorological and microclimatological surveys of cities and their suburbs should be undertaken by local authorities with the assistance of a professional meteorologist. Instruments of standard type should be mounted on existing radio masts at standard heights with measured values presented for standard times in standard units. (1154)
- f. Whenever a meteorological survey is in progress, a continuous record of the magnitude and location of pollution should be provided to permit correlation with meteorological variables. (1154)
- g. The United States Weather Bureau should be encouraged to take more observations of micro-meteorological significance at its stations. Emphasis should be placed on obtaining regular observations of gradients of temperature and wind in the lowest 500 feet of the atmosphere. (1154)
- h. The organization should be undertaken of existing and current literature on all phases of atmospheric pollution so that everyone may be aware of the work of those in other phases. Publication might be in toto or in abstract form. (1154)
- i. If possible, the relationship between wind-tunnel flow and natural atmospheric flow be established. (1154)
- j. The means by which contaminants are removed from the atmosphere be studied in detail. Is the natural cleansing process rapid enough to warrant increasing the rate of disposal of wastes in the atmosphere? (1154)
- k. An aerial survey of the distribution of inversion fog should be undertaken. Atmospheric pollution tends to accumulate over terrain where such radiation fogs are of frequent occurrence. (1154)
- l. Atmospheric electricity should be measured more widely. The conductivity of the air depends on the degree of pollution, and affords a convenient method of studying the secular trends of the latter. (1154)
- m. A general investigation should be made respecting trajectories of the air over a station, and nuclei of various kinds, such as sea salt, radon, pollen, dust, etc. The investigation must be carried out at several stations and at several elevations above ground. (1154)
- n. We must know more about atmospheric characteristics, particularly in and near large and growing industrial centers. Especially important characteristics which must be thoroughly known at all levels into which contaminants are or will be ejected are duration, frequency, and magnitude of stable and unstable lapse rates, and wind direction, gustiness, shear and speed. (1155)
- o. A survey, possibly using aircraft, of the spreading, vertically and horizontally, and the change in concentration of the smoke at different distances would be of much interest. The results would need to be correlated with the meteorological conditions, (1155)
- p. A thorough investigation of the usefulness of radio-wave propagation for the measurement of vertical temperature and humidity structure is particularly promising, since the equipment presumably would not involve the use of fixed towers or masts. (1155)

- q. The determination of the extent to which wind tunnels can be used to simulate atmospheric turbulence by variation of vertical density structure, as well as other parameters, is also worthy of consideration. (1155)
- r. Attention should now be directed more towards the mathematical-physical and experimental study of individual sources, and less towards the statistical survey of a polluted area. The routine observations should continue at all costs, since they form the essential factual basis of the problem. (1155)

U. CLOUDS, FOG, AND AIRCRAFT ICING

1. The Classification of Cloud Forms (W. Howell)

- a. One of the most pressing needs is an approach to a more rigorous logical treatment of the international definitions, making each category of the classification (family, genus, species, etc.) as nearly as possible a geometrical partition. (1165)
- b. Another pressing need is for adequate, uniform training materials and outlines of study. (1165)
- c. The need for an internationally recognized genetical classification is growing. (1165)
- d. It will be necessary to broaden the basis of nephanalysis and make the connection between the structure of nephsystems and cyclones more specific. (1165)

2. The Use of Clouds in Forecasting (C. Brooks)

- a. Better observations and greater attention to interpretation of clouds and their sequence are therefore urged in the interest of improved local and general forecasting. (1167)
- b. For better interpretation of cloud data, we need more detailed cloud charts and many more detailed studies of the sequences of clouds in relation to the development and movement of pressure systems and fronts. (1176)
- c. For better observations, we need more nephoscopes and more ceilometers and range finders. (1176)
- d. Although rocket photography technique is well adopted to desert areas where clouds are thin, it could not do justice to the many layers of damper climates. Perhaps the answer here is television both from above and below! (1176)

3. Fog (J. George)

- a. Our knowledge of the synoptic conditions under which fog forms is far from complete. (1188)
- b. More remains to be done toward establishment of local synoptic studies in fog and refinements of existing studies are easily possible and highly desirable. (1188)

- c. Of primary interest is the desirability of studying in great detail the vertical structure of the lowest layers of the atmosphere to determine the distribution of temperature and humidity and their changes during the formation of fog. (1189)
- d. Our knowledge of the diurnal changes in wind direction and velocity and, what is really the same problem, the relation of vertical wind shear to stability considerations, is still far from a practical solution. (1189)
- e. The different radiative properties of various ground covers and the day-to-day variations in lake and ocean temperatures, while certainly not neglected, have never received the attention which they perhaps merit. (1189)

4. Physical and Operational Aspects of Aircraft Icing (L. Rodert)

- a. The validity and accuracy of the relationships at present employed for determining heat transfer, mass transfer, recovery temperature, and droplet interception should be examined for the full range of values of velocity, shape, and size of aircraft now under design or likely to be designed in the near future. (1195)
- b. An understanding of the nature of thermal ice prevention in greater detail than now exists is needed in order that effective protection may be provided without prohibitive penalties in added equipment to operating aircraft. (1195)
- c. It is of interest to learn what icing conditions are to be encountered at altitudes such as in the tops of cumuliform clouds, and with what degree of severity and frequency icing is apt to be encountered. Data should be collected at altitudes above 25,000 feet on the dimensions and frequency of icing conditions and on the liquid water content, droplet size, and temperature range occurring with icing at these altitudes. (1195)
- d. Reports from military and commercial transport operations supply evidence that some geographical areas are attended by unique icing conditions of severe intensity; therefore, factual data on and a theoretical basis for the variations in the icing problem with geographical locations should be established. (1195)
- e. Inasmuch as water normally freezes at 32°F, it is of prime interest to understand why the droplets in an icing cloud have not undergone the phase change to the solid state and become snow or hail. An effort should be made to identify and analyze the full range of conditions which must be met in order that water droplets may change to ice. (1195)
- f. Improvements in the forecasting of icing are needed as are the means for effectively communicating the forecast to flight-operation centers. (1195)
- g. The understanding of the phenomenon of icing, the design of efficient anti-icing equipment, and the development of reliable techniques of forecasting the occurrence of icing require that accurate and comprehensive data on the factors that produce icing be collected. Although instruments have been developed whereby data of considerable value have been obtained, still further instrumental research is needed. (1195)
- h. In the study of the physics of the icing cloud, instruments that will reveal the existence and size of nuclei, water droplets, and snow crystals are needed. Data on such particulate substances need to be collected in order to reveal their variations with space and time. In the

study of the operational aspects of the icing problem, instruments are needed with which data on the occurrence of icing over wide ranges of geographical location and altitude can be collected. (1195)

5. Meteorological Aspects of Aircraft Icing (W. Leurs)

- a. One of the outstanding problems in the study of icing conditions is that of obtaining satisfactory measurements of the meteorological quantities involved. For example, there is a need for a more convenient and dependable means of determining the distribution of drop sizes in clouds, and also for a more accurate means of measuring mean-effective and maximum drop diameters when these exceed 30 to 40 μ . (1202)
- b. There is also a need for simple dependable automatic instruments for recording liquid-water concentration and average drop size, instruments suitable for use during routine flights to obtain statistical data. (1202)
- c. No adequate explanation is available for the observed facts that certain types of clouds usually contain ice crystals while other types do not, nor is there a satisfactory explanation of the mechanism of the formation of ice crystals in liquid clouds. (1203)
- d. The modifications of clouds that have been accomplished by seeding suggest the possibility that this technique may provide a practicable means of reducing the icing hazard in limited areas, for example in the vicinity of busy airports. Further experiments will be required to establish the practical possibilities and limitations of seeding as a means of locally controlling icing conditions. (1203)
- e. The data now available on liquid-water concentration and drop size in clouds, while sufficient to define in general terms the ranges of values usually encountered, are still inadequate to determine the frequency and severity of icing conditions to be expected in various areas under the influence of various synoptic situations. (1203)

V. METEOROLOGICAL INSTRUMENTS

1. Instruments and Techniques for Meteorological Measurements (M. Ference, Jr.)

- a. Very little data are available on the accuracy of temperature measurements within clouds, using exposed thermistors. The problem has not received the attention that its importance merits. (1213)
- b. The problem of humidity measurements in the free atmosphere is indeed the most difficult one. The opportunities for research in hygrometry are still very great. (1213)
- c. The author is of the opinion that an all-electronic radarsonde system with meteorological computers will represent another major step forward in the radisonde art. (1214)
- d. These basic problems in balloon development are in need of solution: 1) substantial increase in ascensional rates of balloons without impairing other desirable performance characteristics, 2) design of a balloon to reach heights of about 150,000 feet economically and with high degree of reliability, and 3) improvement of the nighttime performance of the synthetic balloon. (1215)

- e. One serious problem for automatic weather stations is an adequate and reliable power source that can operate under a wide variety of climatic conditions. (1218)
- f. To expand the usefulness of unattended stations, additional instrument research is necessary. (1218)
- g. One of the most exasperating if not the most important experimental problem in need of a fresh approach is that of low-temperature hygrometry – the measurement of water vapor to temperatures as low as -80°C , accurately, rapidly, and economically. (1220)
- h. A real need exists for a method of measuring winds on a semiroutine basis at the critical altitudes of 35 to 80 km. The use of smoke trails from V-2 rockets has not been successful at these very high altitudes. (1221)
- i. The question of space integration versus point measurements of temperature and winds is in need of clarification. (1221)
- j. The time has perhaps arrived to give serious consideration to the important problem of data-presentation schemes. The amount of raw data presented to the forecaster for analysis and study is truly staggering. There appears to be general agreement that atmospheric changes are sufficiently complex that a simple representation of them is not feasible at best. (1221)
- k. A careful over-all study of systems should be undertaken at the earliest possible moment. Such a study would include an analysis of methods of obtaining raw data, of systems for data transmission, of possible utilization of analogue and digital computers, and finally a recommendation of an integrated data-presentation scheme. In the opinion of this writer such a cooperative study between system engineers and meteorologists is necessary to insure continuing progress in forecasting techniques. (1221)

2. Aircraft Meteorological Instruments (A. Bemis)

- a. The author believes we now suffer from a serious lack of simple, well-engineered instruments, which might be relatively inaccurate, but nevertheless of great value when commonly available. (1223)
- b. There is a need for inventive genius, good engineering and funds for development work. (1223)
- c. A serious problem exists for the measurement of temperature in the presence of liquid water. (1224)
- d. It is clear that rather complex and specialized instruments are necessary for accurate measurement of liquid water content. (1227)
- e. No satisfactory instrument exists for measuring rain-drop size snowflakes or ice-crystal size and type from aircraft, (1228/1229)
- f. Improvement in this field of endeavor might be accelerated by a more integrated approach, closer coordination among those working in the field, and more unified objectives. It is time, for example, to consider a "one-piece" instrument which would record a number of the quantities we have discussed. (1230)

W. LABORATORY INVESTIGATIONS

1. Experimental Analogies to Atmospheric Motions (D. Fultz)

- a. To make experimental work really fruitful there must be a systematic and sustained effort, guided by theory, to obtain numerical measurements of as great a variety as is practically possible. (1243)
- b. Another basic difficulty with applications of these experiments to the atmosphere has been the lack of simple, theoretical, guiding principles which take into account the thinness of the atmosphere. Experiments need to be designed around principles, even if only semi-quantitatively. (1243)
- c. As experimental work progresses, techniques and altered concepts of the quantities to be measured should develop to a far higher point than is the case at present. (1243)
- d. In connection with general circulation problems, the following experimental steps appear to me to be the next ones to take:
 - 1) The simple types of techniques used in hydraulic or aerodynamic experiments (or in the studies cited above) to measure velocity and temperature should be extended to the cylindrical discs studied by Vettin, Thomson, and Exner. Several modifications would be necessary and height-diameter ratios should be investigated as low values as are possible.
 - 2) The work of Fultz (1949) should be extended to spherical shells incorporating variable depth-radius ratios which Rossby's theory would imply to be important. The data from these experiments need to include much more complete temperature values and also more extensive velocity observations.
 - 3) A most important companion set of experiments to these spherical shell studies needs to be carried out in paraboloidal shells rotated at rates such that the free surface figure coincides with that of the paraboloid.
 - 4) Shearing waves and instability at density discontinuity surfaces in general deserve extensive investigation, in both the rotating and nonrotating cases with various geometrical forms (see, for example, Keulegan (1949)). Here the problem of obtaining velocity measurements of the required density and accuracy for meteorological application is very serious. (1244/1245)
- e. Concerning smaller-scale problems it appears that important work could be done on vortices (tornadoes and hurricanes) by careful measurement of field quantities around one or the other of the experimental cases. (1245)
- f. There exist at least two fields in which the possibilities of significant experimentation seem very large and which, from the meteorological angle, are just opening up at the present time:
 - 1) One of these is the field of hydraulic and supersonic gas flow analogies, opened for meteorology by Freeman (1948).
 - 2) The second field is one in which hardly anything of meteorological significance has yet been done experimentally, but in which many possibilities must exist. This area is that of electromagnetic analogies. (1245)

2. Model Techniques in Meteorological Research (H. Rouse)

- a. Through the many professions dealing with fluid motion, there has been obtained a considerable amount of experience with scale-model investigations, which should be of use in developing comparable procedures for research in the field of meteorology. The general principles of dimensional analysis at once indicate the criteria for similarity of the various pertinent flow phenomena, and at the same time serve as a guide for effective research. Likewise, the closely related aspects of many problems in fluid motion make various techniques developed in other fields directly applicable to that in question. In other words, the scale model is now an established rather than an untried scientific tool, and the problem is one of adaptation of somewhat new requirements rather than of complete origination. (1254)
- b. At present writing it appears that meteorologists could profitably expand, according to their own requirements, many aspects of model investigations already proven useful in related fields. These include studies of both the mean flow pattern and the eddy structure produced by irregular boundary configurations; research in diffusion of heat and vapor by both forced and free convection; experiments on stratified flows; and, at least in an exploratory manner, the simulation of conditions which combine two or more such effects. To what extent attainment of the Reynolds criterion of viscous similitude may become possible for other boundary conditions, and whether or not thermodynamic similarity may also become practicable, must be decided in the future. In any event, the profession can rest assured that the perfection of meteorological model techniques will open many an avenue of fruitful study hardly conceivable in advance. (1254)

3. Experimental Cloud Formation (D. Brunt)

- a. The most desirable investigations would be the collection of details of variation of temperature and wind with height within the types of cloud discussed, the depth of the cloud layer being carefully measured at the same time. (1261)
- b. The essential details of the laboratory phenomena have been collected, but the theoretical discussions referred to fail to lead to such results, (1261)

X. RADIOMETEOROLOGY

1. Radar Storm Observation (M. Ligda)

- a. The value of radar for weather observation can be greatly enhanced by increasing the range through suitable location of the systems. (1279)
- b. Because of the ease of radarscope interpretation in location of the position of precipitation areas, television may be an excellent medium by which to convey the image of the PPI scope to the citizen for his own interpretation. (1280)
- c. A possibly valuable application of radar storm detection exists in the field of water conservation, flood control, and irrigation. (1280)
- d. The usefulness of radar for storm detection can be greatly amplified by improving equipment as well as observational techniques. Many instruments and accessories developed for special applications have not yet been tested for their utility in radar storm detection work. (1280)

- e. Horizon-to-horizon RHI scope used in conjunction with an antenna which scans from horizon to horizon through the zenith, would greatly improve the cross-section display presently available to the observer. (1280)
 - f. At present, one of the main restrictions on the use of radar for storm-detection information by weather forecasters is the lack of suitable means of disseminating the scope information to all persons interested in it. (1280)
 - g. It is anticipated that radar will provide useful information concerning the structure and behavior of that portion of the atmosphere which is not covered by either micro- or synoptic-meteorological studies. Phenomena of this size might well be designated as meso-meteorological. (1281)
 - h. In addition to supplying observations in this mesometeorological region, radar is also expected to be of assistance to the physical meteorologist in his studies of the mechanism of precipitation; of the size and number distribution of hydrometeors; and of the behavior of hydrometeors under various conditions of turbulence. It may also provide him with clues concerning the processes of waterdrop and snowflake growth, coalescence, and evaporation. (1281)
2. Theory and Observation of Radar Storm Detection (R. Wexler)
- a. It would be particularly desirable to measure the rate of decrease with altitude of the signal strength from different clouds of varying depths, precipitation intensities, and atmospheric conditions. Such measurements would give information on the growth of precipitation particles by diffusion and the magnitude of the coalescence effects. (1289)
 - b. Simultaneous radar and visual (theodolite) observations of cumuliform clouds, similar to those carried out by Workman in New Mexico, should also lead to a better understanding of thunderstorms. Fruitful research problems are: 1) the rate of rise of the visual top as related to the echo top in growing thunderstorms, 2) coagulation and chain reaction effects in the heavy rain, again as revealed by the rate of decrease with altitude of signal strength, and 3) the characteristics of precipitation echoes during the formation of the bright band in the degenerate stages of the thunderstorm, as revealed by radarscope photographs taken with reduced gain. (1289)
3. Meteorological Aspects of Propagation Problems (H. Booker)
- a. From what has been said it is clear that we need to be able: 1) to recognize those situations which involve a temperature inversion exceeding about 5°F per 100 feet within a few thousand feet of the earth's surface, 2) to recognize those situations which involve a lapse rate of humidity exceeding about $1/2 \text{ g kg}^{-1}$ per 100 feet within a few thousand feet of the earth's surface, 3) to state, within say 10 feet, over what interval of height the gradients exceed the values mentioned, 4) to state to an accuracy of say 10 percent or 10 feet, whichever is cruder, the height above the earth's surface at which the step gradients occur, and 5) the complete profiles of temperature and humidity, with an accuracy indicated by the requirements listed above, are highly desirable, together with their statistical variations. (1294)
 - b. The problem is therefore to obtain such a fundamental understanding of how the profiles of temperature and humidity near the base of the troposphere are controlled by such parameters as temperature excess, humidity deficit, wind speed, etc., that knowledge of the values of these parameters is adequate to provide answers to at least four requirements stated above. (1294)

- c. We need to understand the phenomena of subsidence, advection, and nocturnal radiation sufficiently well to form a workable theory of the associated profiles of temperature and humidity. (1294)

4. Sferics (R. Wanta)

- a. More studies are needed relating broad meteorological patterns to the distribution of thunderstorms and other intense electrical activity occurring in regions of rapid charge separation. The physical nature of the lightning flash, its visible and photographic forms, the resulting field changes, the propagation of attending electromagnetic waves – these researches have been and are still emphasized. (1299)
- b. If the field of sferics is to find important use in meteorology, studies of regional application of sferics observations to characteristic weather patterns must be undertaken; reference is made to the areal distribution of thunderstorms attending the large-scale flow patterns. (1299)
- c. The development of a synoptic climatology of sferics distribution over the oceans would contribute toward maximum utility of sferics methods. Great benefit should also be derived from the analysis of wave forms that indicates the relative frequency of cloud-to-cloud, cloud-to-air, and cloud-to-ground discharges. (1299)
- d. Sferics study promises to refine our knowledge of the distribution of thunderstorms over the oceans. (1299)
- e. The development of a climatology of radio static appears desirable. It should become possible to estimate reasonably well for any given place on the globe the monthly, seasonal, and annual noise level, and its diurnal variation. (1299)
- f. Rapid techniques for handling the considerable volume of information obtained even with a simple direction finder will increase the utility of sferics in applications to forecasting. (1299)
- g. It would be helpful to investigate the proper length of observational sample necessary in order to obtain a reasonably complete picture of the sferics activity occurring at a given time. (1299)

Y. MICROSEISMS

1. Observation and Theory of Microseisms

Many important studies remain to be undertaken. Among those in which progress would be most helpful are the following:

a. Empirical Studies (1310)

- 1) More detailed studies on types of microseisms and their causes.
- 2) Study of wave types and characteristics of observed microseismic waves and determination of the "spectrum" of microseisms at a variety of locations.
- 3) Determination of the direction of approach of microseismic waves of various types at different stations by use of tripartite stations and different types of instruments at a given station.

- 4) Additional determinations of velocities of microseismic waves and their correlation with velocities of seismic waves found from earthquakes and from blasts in the same region.
- 5) More data on the relationship between the periods of the cause of microseisms in specific instances and the periods of the recorded microseismic waves in various parts of their "spectrum."
- 6) Study of the relationship between microbarometric waves and microseisms (only a few data exist).
- 7) Measurements of pressure variations at greater depths in the ocean and their correlation with ocean waves at the surface (amplitudes and periods) as well as with microseisms recorded nearby on land.

b. Theoretical Studies (1310)

- 1) Study of the effect of free vibrations of the ground on microseismic waves, especially resonance effects. (This is a minor problem for earthquake waves where there are rarely "continuous" waves within the range of periods prevailing in microseisms.)
- 2) Quantitative data on effects of maximum or minimum group velocity on amplitudes (Press and Ewing's theory, 1948).
- 3) Extension of the theory of Press and Ewing to other models, especially under assumption of a gradual or sudden increase of velocity with depth in the materials which form the ocean bottom.
- 4) Study of the transition of elastic waves from one structure to another, for example, gradually or suddenly from a model of the type considered by Press and Ewing to a typical continental structure.
- 5) Study of the transition of surface waves from one structure to another with different elastic constants down to a depth of a fraction of the wavelength and a multiple of the wavelength.

2. Practical Application of Microseisms to Forecasting (J. Macelwane)

- a. Quite contradictory conclusions have been drawn from parallel correlations. Much the same may be said of vectorial analysis of microseismic records. A very fruitful line of research has been opened up by the use of tripartite stations whose dimensions are less than one wavelength. This method is independent of all assumptions except the successive arrival of an identical wave front at the three corners of the tripartite station. (1315)
- b. Research on the origin of the microseisms or the mechanism by which they are produced is difficult but very necessary. (1315)
- c. The possibility of air oscillations acting as a hammer may be investigated by means of microbarographs disposed on small islands in the path of typhoons and hurricanes. A similar system for the investigation of standing waves, or of the oscillations of a water vortex, would be much more difficult and costly. (1315)

III. SUMMARY COMMENTS

The subject of using satellites to support studies of problems in meteorology does not appear in any of the articles to the best of my recollection. However, the authors reflected on what must be recognized as outstanding accomplishments and especially so when we consider that they were made without the benefit of the high technology and computer resources of today. While I may have overlooked some of the key scientific issues and problems in the articles, one can still recognize many of those identified as still being with us today. Some have been resolved or solved but many are still awaiting solution. Have we made enough progress in the past thirty-five years to warrant the magnitude of resources which have been devoted to research on meteorological scientific issues and application problems? I will leave the answer to those reading this paper and their reflections on the significance of progress made on the issues noted as they see it within their frame-of-reference.

One final comment. It would seem that the time is appropriate for the undertaking of a second edition of the Compendium of Meteorology. Maybe it could be published in parts due to the magnitude of literature available on some topics. Given the value the first edition provided to students and researchers, and the historical reference it has also provided, I believe a second edition would be an excellent contribution to the field of meteorology at this time. It would be no small undertaking as I am sure the original authors and committee would agree. However, I believe it will be a most valuable project. Perhaps the National Academy of Science, National Science Foundation, Department of Defense, National Oceanic and Atmospheric Agency, and National Aeronautics and Space Agency would find co-sponsorship of the project a valuable and worthwhile endeavor given their strong interests in the subject. An alternative to a complete Compendium of Meteorology publication would be to consider preparing monographs organized around each of the various technical sections of the Compendium of Meteorology plus perhaps a few new ones in Satellite Meteorology, Aerospace Meteorology, etc.

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16. ABSTRACT The Compendium of Meteorology was published in 1951 by the American Meteorological Society. A review was made of the Compendium of Meteorology to identify the studies and future research needs which the various authors expressed in their papers. The needs as seen by the authors are organized into sections and papers following the format of the Compendium of Meteorology. In some cases the needs they identified are as valid today as they were in 1951. In other cases one will easily be able to identify examples where significant progress has been made. It is left to the individual scientists and scientific program managers to assess for themselves whether significant progress has been made over the past thirty-five years on these outstanding scientific issues.					
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